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Dissolved Oxygen Impact from Urban Storm Runoff

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The primary objective of the research reported here is to determine if on a national basis a correlation exists between strength of dissolved oxygen (DO) deficits and the presence of rainfall and/or storm runoff downstream of urban areas. A secondary objective is to estimate the magnitude and extent of the problem.

One hundred and four water quality monitoring sites in and downstream of urban areas throughout the country were considered for inclusion in the study. These were screened from over 1000 monitors maintained by federal and state agencies such as the U.S. Geological Survey, Environmental Protection Agency (EPA), Ohio River Valley Sanitation Commission and Wisconsin Department of Natural Resources. Daily data were obtained and processed for 83 of the 104 candidate sites. Of the 83 monitors considered, 42 percent or roughly four monitors in ten of the 104 candidates demonstrated a 60 percent or greater probability of a higher than average DO deficit occurring at times of higher-than-average stream flow or on days with rainfall. In general, the data examined here indicate that 19 percent of the 104 candidate monitors might not meet a 5.0-mg/l standard and 15 percent might not meet a 2.0-mg/l standard. Frequency of violations was not tabulated exactly but appears to be zero to five times per year at sites with correlations.

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Contract No. 68-03-2630

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communications link between the researcher and the user community.

This report investigates the correlation between storm runoff and dissolved oxygen deficits downstream of urban areas. Several hundred station years of water quality monitor flow and rainfall data obtained by the U.S. Geological Survey, the U.S. Environmental Protection Agency, the National Weather Service and other government agencies are used in the study.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

The primary objective of the research reported here was to determine if on a national basis a correlation exists between strength of dissolved oxygen (DO) deficits and the presence of rainfall and/or storm runoff downstream of urban areas. A secondary objective was to estimate the magnitude and extent of the problem.

One hundred and four water quality monitoring sites in and downstream of urban areas throughout the country were considered for inclusion in the study. These were screened from over 1000 monitors maintained by federal and state agencies such as the U.S. Geological Survey, Environmental Protection Agency (EPA), Ohio River Valley Sanitation Commission and Wisconsin Department of Natural Resources. Daily data were obtained and processed for 83 of the 104 candidate sites. Of the 83 monitors considered, 42 percent or roughly one monitor in two had data which demonstrated a 60 percent or greater probability of a higher than average DO deficit occurring at times of higher-than-average stream flow or on days with rainfall. This result was obtained by considering daily data for entire water years. Not all years at any given station exhibited a 60 percent probability. One to three years out of five is typical. DO levels fell to less than 75 percent saturation at most of the sites where 60 percent or greater probability existed. Levels of 5 mg/l or less were not uncommon.

Detailed hourly data analysis was made at 22 of the sites with high correlation between flow and DO deficit. Typically, at times of steady low flow the DO fluctuates widely on a daily cycle. These cyclic changes range from 1 to 7 mg/l. When a storm event occurs and the flow increases, the diurnal cycle disappears. The minimum DO drops from 1 to 1.5 mg/l below the minimum values observed during steady flows and remains constant there for periods ranging from one to five days. As the flow event subsides, the DO level resumes its cyclic behavior. Of the 22 monitors examined on an hourly basis, 11 would not meet a 5.0-mg/l DO standard. Six of the 11 would not meet the EPA-suggested 2.0-mg/l-for-four-hour standard. Streeter-Phelps analysis indicated that two additional monitor sites at which hourly data were examined would not have met the EPA standard had they been properly located. An additional two sites at which hourly data could not be obtained would also not have met the EPA standard.

In general, the data examined here indicate that 19 percent of the 104 cnadidate monitors might not meet a 5.0-mg/l standard and 15 percent might not meet a 2.0-mg/l standard. Frequency of violations was not tabulated exactly but appears to be zero to five times per year at sites with correlations.

The data base from which this study was drawn is not geographically homogeneous. By far, the largest number of monitors is in the midwest and northeast. Less than one-half of the states are represented. No conclusions can thus be drawn on the national scope of either correlations or standards violations. Further study of monitor sites with both strong correlations and standards violations is recommended to specifically identify causes. The frequency of standards violation appears to be low, but the causes should be identified to prevent the frequency from increasing.

This report was submitted in partial fulfillment of Contract No. 68-03-2630 by the Sutron Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from November 18, 1977 to May 1, 1979 and work was completed as of May 1, 1979.

CONTENTS

Foreword iii
Abstract iv
Figures viii
Exhibits viii
Tables ix
English to Metric Conversion Units xi
Acknowledgments xii

1. Introduction 1
2. Summary of Findings 6
3. Conclusions 9
4. Recommendations 11
5. Site Location and Screening 13
6. Daily Correlation Analysis 26
7. Detailed Site Analysis 57
8. Assessment of Extent and Causes of Problem 76

References 94
Appendices

A. Water quality data collection agencies 96
B. Monitor sites considered for analysis 119
C. Results of daily correlation analysis 128
D. Results of detailed site analyses 152

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FIGURES

No. Page

1. Card format used by National Climatic Center for weather data 33

2. Typical daily flow and DO records illustrating high degree of correlation between high flow and low DO 41

3. Box or compartment method used to analyze daily data for correlation between high flow and low DO. . . 43

4. Streeter-Phelps analysis results for Scioto River at Chillicothe, OH 69

5. One month of hourly data for the Scioto River at Chillicothe, OH 74

6. Hourly data for one-month period, Scioto River at Chillicothe, OH 75

7. DO/flow correlation on the Little Miami River near Spring Valley, OH 79

8. Probability of low DO at high flow versus percentage of urban area 87

EXHIBITS

No. Page

1. Tape File Structure Description, ORSANCO Data . . . 39

2. Site Analysis Form - Streeter-Phelps 59

3. Site Analysis Form 60

TABLES

No. Page

1. OWDC Regions and Number of Agencies Collecting Water Quality Data 15
2. List of All Sites Considered for Daily or Hourly Analysis 23
3. Study Code Classifications 24
4. USGS, 1,656-Byte, Magnetic-Tape Output Format 28
5. Record Arrangement on Disk File for STORET MORE = 4* 32
6. Card Image Content for National Climatic Center Weather Data 34
7. Data Block Structure, ORSANCO Data 38
8. Eligible Sites not Analyzed and Reasons. 47
9. Monitor Sites Exhibiting a 60 Percent or Greater Probability of Low DO During High Flow or Periods of Rainfall 49
10. Monitor Sites with 60 Percent or Greater Probability of Low DO at Times of High Flow 50
11. USGS Monitor Sites with 60 Percent or Greater Probability of Low DO on Days with Rainfall 53
12. Streeter-Phelps Analysis Sites 68
13. Sites at Which Hourly Data Were Processed 70
14. Monitor Sites at Which DO Levels Below 5.0 mg/l Were Observed 81
15. Monitor Sites at Which EPA DO Standards Were Not Met During Runoff Events 81

TABLES (CONTINUED)

No. Page

16. Monitor Sites with Potential for EPA Standard Violations If Properly Located 82

17. Problem Sites Per State Versus Number of Monitors Per State 85

18. Sites Recommended for Further Study 90

ENGLISH TO METRIC CONVERSION UNITS

cfs x 0.02832 = m^3/s

ft x 0.3048 = m

in. x 2.54 = cm

mile x 1.609 = km

sq. miles x 2.590 = km^2

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SECTION 1

INTRODUCTION

BACKGROUND

Dissolved oxygen (DO) levels have long been taken as indicators of the health of a water body. The aquatic plant and animal life depend on the presence of minimum DO levels. A stream's ability to assimilate waste is largely a function of available DO.

In the initial efforts to clean up the nation's waters and meet DO standards, attention was focused on point source waste discharges. It was generally believed that upgrading sewage treatment plants and industrial outfalls to a high treatment level would restore water quality. There is little question that these efforts were beneficial. However, as more and more point sources have come under control, it has become evident that nonpoint waste sources are also significant.

The exact effect of urban nonpoint runoff on DO levels is difficult to quantify for several reasons. The phenomenon is highly transient in nature. How and what enters a receiving water is a function of the type of urban activity, land use, time between storms, distribution of rainfall, collection methods, and numerous other factors. Urban runoff may enter a receiving water directly through storm sewers or through combined storm/sanitary sewers.

The combined sewers represent a particularly complex problem. These route both storm runoff and sanitary waste to a central treatment facility. At times of peak flow, the sewer is designed to overflow directly into a receiving water. These overflows may occur at the treatment plant or at a variety of places in the urban drainage system.

Studies in Durham, North Carolina (1), indicate that direct urban runoff is no more desirable than sanitary sewage. Urban surface waters receive substantial amounts of organics, solids, nutrients, heavy metals, and microorganisms. It is not surprising then that stream quality may be adversely affected downstream of urban areas after a storm event even in the presence of advanced wastewater treatment.

The research presented here is designed to determine, as far as possible, the behavior of DO levels downstream of urban areas after storms.

SCOPE AND OBJECTIVES

The original scope of work divided the study into six interrelated areas. The first and major area was to examine available, continuously recorded water quality information in data banks such as U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency's (EPA) STORET system. Data from other state and local agencies such as the Ohio River Valley Sanitation Commission (ORSANCO), Wisconsin Department of Natural Resources (WDNR), Greater Metropolitan Chicago Sanitation District and others were to be considered when possible. The data bases were to be reviewed to obtain a five-year historical picture of DO, temperature, and flow in the receiving waters of the United States at the location of all reliable continuous water quality monitoring stations. Concurrent with this review, five years of hourly rainfall data for the areas in which the monitoring stations are located were to be obtained from the National Climatic Center in Asheville, North Carolina, or other sources. The DO and temperature records were to be examined to find all locations downstream of urban areas in which the DO during the warm weather portion of the year fell to less than 75 percent of saturation. At these locations, an analysis was to be made to determine whether a correlation exists between wet weather discharge and DO sag and how significant the wet weather impact is.

The second area of study recognized the fact that existing monitors are not necessarily located to study urban runoff. The location of the monitoring stations and rain gages relative to the urbanized areas and the relative sizes of urban and nonurban drainage areas contributing to the receiving water were to be considered in making judgments about urban rainfall/runoff and DO deficits.

The third study area was to determine the accuracy and reliability of the monitors used in the research. Inoperative periods and frequency of maintenance were variables to be considered.

The fourth component of the Scope of Work was a reemphasis of the need for studying hourly variations in the variables of interest. Study of daily averages to determine whether a monitor was to be included in the study was permissible but hourly values were to be used in the final analysis.

The fifth study area was to perform an in-depth analysis of sites with a strong high flow, low DO correlation. The traditional Streeter-Phelps (Thomann (2) p. 110) technique was to be used to determine if severe oxygen sags could be caused by the particular urban area and how many stream miles (Kilometers - see conversion factors page 238) are affected.

The final study area was to analyze the study results on a national basis and attempt to estimate the overall impact of urban storm runoff. The analysis was to be stated in terms of stream miles affected, if possible.

For the most part, the Scope of Work was carried out as originally intended. Modifications were made primarily to recognize the very large number of monitors available with less than the five years of continuous data and those without hourly rainfall data. The need for this modification became apparent early in the study. For instance, the USGS maintains over 100 water quality monitors. Only 12 had five years of record, were in close proximity to a stream gage, and were within reasonable distance of a primary weather station where hourly rainfall data were available. By modifying Area 1 of the Scope of Work to include monitors with five years or less of data, the number to be considered increased significantly. This required a greater emphasis on daily analysis to keep the total amount of data values manageable. As stated in the fourth area of the Scope of Work, each station was examined on a daily average basis for inclusion in the study. Periods of hourly data ranging in length from 240 to 720 hours at sites with strong correlation between flow or rainfall and low DO were then examined.

The major objective of the study was to determine on a national basis the impact of urban runoff on DO levels in receiving waters. Data from point-specific studies such as the Triangle J Joint Council of Governments "208" waste management plan (3) have indicated a strong correlation between periods of low DO and high stream flow. Similar results have been obtained in other locations (Texas (4), Missouri (5)). It was hoped that by examining existing water quality monitor records that a broad national picture of the problem could be obtained if, indeed, one existed.

DEFINITION OF PROBLEM DO LEVELS

The exact definition of a low DO level is subject to some debate. The definition is largely a function of the intended use. Thomann (2) summarizes several representative standards. The Ohio River Sanitation Commission requires that the dissolved oxygen should not be less than 5 milligrams per liter (mg/l) during at least 16 hours of any 24 nor less than 3 mg/l at any time in the upper basin areas. In the industrialized lower basin and estuary region, a level of 3.5 mg/l must be maintained on a daily average basis. The National Academy of Sciences Committee on Water Quality Criteria (6) recommends a minimum level of 4 mg/l at all times and other higher criteria based on the "natural seasonal oxygen minimum."

The U.S. Environmental Protection Agency has supported considerable research on DO levels and their effect on aquatic life. The DO criteria proposed by EPA for freshwater aquatic life are given as follows:

> "Freshwater aquatic life: A minimum concentration of dissolved oxygen to maintain good fish populations is 5.0 mg/l. The criterion for salmonid spawning beds is a minimum of 5.0 mg/l in the interstitial water of the gravel." (7)

Research has established that DO concentrations as low as 2 to 3 mg/l can be tolerated for short duration. Thus, minimum DO levels and allowable frequency of exceedance have been established. The DO level-duration relationship is based on measured survival times of juvenile brook trout when subjected to lethal DO levels. Juvenile brook trout are a very sensitive indicator species.

The EPA DO criteria based on the survivability of brook trout are as follows:

> "The minimum receiving water dissolved oxygen concentration shall not average less than 2.0 mg/l for more than 4 consecutive hours; nor shall the minimum receiving water dissolved oxygen concentration average less than 3.0 mg/l for more than 72 consecutive hours (3 days). In addition, the annual average receiving water dissolved oxygen concentration shall be greater than 5.0 mg/l for all waters which will support warm water species and shall be greater than 6.0 mg/l for all waters which will support cold water (salmonid) species." (7)

Simulation studies indicate that if the criterion of 2.0 mg/l for 4 consecutive hours is met, then, in general, all other criteria will be met. An allowable frequency of exceedance of the 2.0 mg/l criteria of one four-hour period per year is the basis for biological oxygen demand (BOD) removal requirements.

For the purposes of the this study, DO levels of less than 5.0 mg/l will be referred to as low DO or poor water quality. Sites at which the standard of 2.0 mg/l for more than four consecutive hours is violated will be referred to as problem sites.

The question of what constitutes a problem is important in an economic sense. Since the existence of a problem implies the necessity of a cure, in this case treatment of urban runoff, considerable dollars are involved. It was an important part of the study, if not a secondary objective, to carefully examine "problems" before concluding the cause to be urban runoff.

SECTION 2

SUMMARY OF FINDINGS

CORRELATION OF LOW DO WITH FLOW AND RAINFALL

Daily correlation analyses using either flow or rainfall or both were attempted at 104 stations. These included USGS, STORET, and WDNR data. Of these, 83 had sufficient data to produce results. These included 55 USGS monitors, 17 STORET monitors, and 11 WDNR monitors.

Of the USGS monitors, 19 exhibited a 60 percent or greater probability of low dissolved oxygen at times of high flow. Eighteen exhibited a 60 percent or greater probability of low DO on days with rainfall. Eight of the stations correlated with both flow and rainfall. The total number of stations exhibiting either type correlation was 30.

Of the 17 STORET monitors, three exhibited a 60 percent or greater probability of low DO at times of high flow. Of the 11 WDNR monitors, three exhibited the 60 percent or greater probability.

Out of 104 candidates for analysis, 36 gave positive results in the correlation analysis. Twenty-one of the monitors could not be correlated because of data problems. Thus, 42 percent of the monitors successfully examined or 36 percent of the likely candidates gave positive correlation results. For discussion purposes, it is thus concluded that four monitors in ten placed near an urban area might indicate lower than average DO at times of storm runoff.

MAGNITUDE OF DO DEFICITS

Because of the coarse time resolution of the daily data, no direct conclusions could be drawn concerning the severity of the DO deficits which sometimes accompany high flow or rainfall. Examination of hourly data at sites with strong daily correlation indicated that water quality violations can occur. Of the 30 USGS sites, 11 clearly indicate a severe DO deficit at times of high flow. Eleven additional sites clearly indicate an effect from storm runoff but could not be classified as severe.

Several of these were judged to be too close to the urban area to detect the maximum deficit in the Streeter-Phelps sense. Six of the sites did not have water quality problems, at least concerning DO. Some depression during storm events would usually be seen.

CHARACTERISTICS OF DO VARIATIONS

Although the eleven sites with severe problems varied widely in size and physical setting, all demonstrated remarkably similar hourly data records. The period prior to a storm event is characterized by fairly large diurnal cycles in the DO level; fluctuations of 4 to 5 mg/l are not unusual. Periods of supersaturation are often indicated. As the flow increases, the diurnal cycles in the DO record disappear. This may be due to increased turbidity and depth cutting off the sunlight to the aquatic plant life at times of high flow.

At the time of peak flow, deficit levels at least equal to and occasionally 10 to 15 percent higher than the peak diurnal cycle value are reached.

The effect of the storm flow on the DO level lasts quite a long time. This long-term effect gives added validity to the daily analysis procedure. Sites at which a single hydrograph peak was examined usually recovered in three to five days.

COMPARISON OF STORM FLOW DEFICITS AND QUALITY STANDARDS

When measured against existing stream quality standards, the DO deficits accompanying storm flow may cause water quality violations. Hourly data at monitor sites with strong correlation consistently show deficits below 5.0 mg/l extending over several days. The Streeter-Phelps analysis of 10 sites, including several with strong correlations, consistently indicated that monitors are not ideally placed to sense maximum effects. In many cases, deficits 30 to 50 percent stronger could theoretically be found.

Storm-flow-related deficits at some sites consistently violate 2.0 mg/l - 4 hour standards. In fairness, it must be pointed out that at these sites the water quality is marginal at all times. Storm events merely push the level down further. General improvements in water quality at all the critical sites would help alleviate the problem.

NATIONAL DISTRIBUTION OF SITES

The question of whether dissolved oxygen deficits caused by urban runoff is a national problem is difficult to answer. One item to consider is the geographic coverage of this study.

The USGS data base maintained at the Reston, Virginia, Headquarters contains records for 150 water quality monitors. These monitors are located in 30 of the 48 conterminous states or 63 percent coverage. The distribution of states containing monitors is highly nonuniform. Thirteen states are east of the Mississippi River and 17 are west. Only 47 of the 150 monitors are in western states. If the dividing line between east and west is considered to be along the western boundaries of Louisiana, Arkansas, Iowa, and Minnesota, the distribution becomes even more unbalanced. Only 19 monitors are then located in the west.

The distribution of monitors by state is highly nonuniform also. Ohio alone has 32 monitors, followed by New Jersey with 13 and Louisiana with 11.

It was ultimately concluded that the existing monitor network is probably inadequate to define a national problem. The probability is approximately one in three of detecting a correlation between flow and DO deficit. Many states with significant urban areas on streams have no monitor records at all in the major data banks.

SECTION 3

CONCLUSIONS

Several hundred station-years of DO, stream-flow, and temperature data from locations around the United States have been analyzed to determine if a correlation exists between DO deficit and either flow and/or rainfall downstream of urban areas. In the first portion of the study, daily average data were used to select stations where a high probability existed of the simultaneous occurrence of higher than average flow and/or a rainfall event and DO deficit. In the final portions of the study, hourly flow, rainfall, and DO data were examined at those sites exhibiting a high probability. The hourly data examination was used to more clearly identify the nature of the correlation. In addition, a Streeter-Phelps analysis was made at selected sites to determine if a particular water quality monitor was in the best location to detect DO deficits from an urban area. The following conclusions were drawn from the study:

- The probability is approximately one in three that analysis of data from a currently existing water quality monitor in or near an urban area will show a correlation between high flow and/or rainfall events and high DO deficit.

- In close examination of sites that exhibited daily correlation between flow and low DO or both rainfall and flow and low DO, strong visual evidence was usually found of the correlation in hourly data records. Sites that exhibited daily correlation with rainfall seldom showed any visible evidence of correlation in hourly data records. Flow was judged the better correlation parameter because it is a direct rather than a secondary indicator of stream conditions.

- At stations where correlation exists, maximum deficits observed during periods of high flow are equal to or 10 to 15 percent greater than the maximum deficits observed during diurnal cycles at times of steady low flow.

- At locations where water quality is already marginal (e.g., 5-7 mg/l DO), a storm event can result in DO levels less than 4-5 mg/l for periods of several days or longer. Occasional violations of 2 mg/l - 4 hour standards occur.

- Most water quality monitors are located too close to the urban areas to detect the maximum possible DO deficit in a Streeter-Phelps sense.

- Flow and DO deficit are correlated in a wide variety of urban situations ranging from towns of 20,000 population to urban megalopolises of greater than 1 million population.

- The absence of a correlation between flow and DO deficit does not correlate well with the percentage of contributing urban areas in the drainage basin. There are exceptions in extreme cases where 50 percent or more of the contributing area is urban.

- There is no reliable way to extend the results of this study to an estimate of total affected stream miles nationally. No government agency currently publishes data on the distribution of population along major rivers.

- The probability of a high DO deficit occurring at times of high flow is not demonstratably greater during the summer months.

- In most instances, the exact cause of the increase in DO deficit is not obvious. In some cases, there are heavy concentrations of industry along the stream channel. In other cases, a sewage treatment plant is close upstream. Reintrainment of benthic material is a likely cause in such locations. In other instances, there is no industry or sewage treatment shown on the site maps. Here, the problem may be strictly due to BOD of urban runoff, a chemical oxygen demand, or other problems.

SECTION 4

RECOMMENDATIONS

The resources of this study were directed primarily at determining if a correlation exists between increased flow and/or rainfall events and increased DO deficit below urban areas. This fact was reasonably well established at a number of locations. At several of these locations the dissolved oxygen levels were low enough to violate water quality standards. The following recommendations are made in an effort to determine why such a relationship exists:

- More-detailed investigations should be undertaken at three to five of the sites with strongest correlation. These investigations should include: (1) a field study of the river reach through the urban area to the monitor; (2) studies of the industrial waste and sewage treatment practices along the reach; (3) details on the drainage systems from the urban areas; (4) population density, climate, and other pertinent data.

- Sites specifically identified as worthy of study include the Cuyahoga River between Akron and Cleveland, Ohio; the Scioto River between Columbus and Chillicothe, Ohio; the Mahoning River below Youngstown, Ohio; the Sandusky River below Upper Sandusky, Ohio; and six other sites with hydraulically complex conditions.

- The data base created as part of this study has considerable value. Consideration should be given to publishing a short report on the data base and making it available along with digital magnetic tapes of the data.

- A project should be undertaken at one site with a strong correlation to develop an adequate data set to support an unsteady flow water quality model. Streeter-Phelps analysis is not an accurate representation of water quality behavior under storm conditions. "Adequate" data set does not mean historical data collected by random agencies at random times and places. It means a concerted effort to obtain synoptic or near-synoptic values of pertinent water quality variables in a way designed for use with a model. Such a data set would allow meaningful investigation into the exact behavior of the DO deficit and the oxygen-demanding material during storm flow.

- Even in the absence of a modeling effort, further cause-effect type data would be valuable at sites with strong flow-DO correlation. It would be particularly valuable to determine if the cause is nonpoint runoff, treatment plant bypass, reintrainment of settled industrial waste, combined sewer overflow (CSO), or other causes.

SECTION 5

SITE LOCATION AND SCREENING

Locating agencies that maintain data bases of water quality information and screening for relevant material required a significant amount of effort. This section identifies those sources that were contacted, describes the type of data available, and outlines the procedure for selecting sites for inclusion in this study.

The following paragraph from the Scope of Work clearly describes the required tasks:

> "Available, continuously recorded water quality information in data banks such as EPA's STORET system and USGS's NAWDEX system and from other sources and agencies such as the Ohio River Sanitation Commission (ORSANCO) that operate monitoring stations shall be reviewed to obtain a five (5) year historical picture of dissolved oxygen, temperature, and flow in receiving waters of the United States at the locations of all reliable continuous water quality monitoring stations. Concurrent with this review five (5) year hourly rainfall data for the areas in which the monitoring stations are located shall be obtained from the National Climatic Center in North Carolina and the National Weather Service in Maryland, or from other available sources."

The requirement for five years of data was subsequently relaxed, but initially the project proceeded as directed above.

In order to comply with this segment of the Scope of Work, a search of the listed agencies was begun. During the course of the search, other sources were discovered and in turn searched for pertinent data. The quantity of information available is quite large and cannot practically be presented here, even as an appendix. Instead, each agency that provided useful input to the study will be discussed individually. Relevant names and addresses are provided so that the interested reader can obtain more-detailed information if desired. Idiosyncrasies of the system, if any, are mentioned. After describing the various information banks, the screening procedure will be described.

AVAILABLE DATA BASES

Office of Water Data Coordination (OWDC)

The Office of Water Data Coordination is under the Department of the Interior. It is part of the Water Resources Division of the USGS. Its nominal mission is to "coordinate federal activities in the acquisition of certain water data." The OWDC is located in the USGS National Headquarters at Reston, Virginia. Inquiries may be mailed to the USGS Headquarters, Mail Stop 417. At the time of this writing, Russell H. Langford was in charge of the operation.

The OWDC compiles a catalog of water data collection stations throughout the United States. Water quality and quantity monitors for streams, lakes, reservoirs, estuaries, and ground water are included. It publishes a 21-volume set of "Catalog of Information on Water Data," the most recent dated 1974. Another set was under review but was not available for this study. These 21 volumes correspond to 21 regions of the country. These 21 regions, along with the number of federal, nonfederal, and Canadian agencies contained in each, are listed in TABLE 1.

The OWDC catalogs draw information from many sources including federal agencies, state and local agencies, and Canadian agencies. The following statement appears on page 2 of each catalog:

> "Although not all non-federal agencies acquiring water data were contacted, the district offices attempted to include those agencies most active in water-data acquisition in each state, thereby, deriving extensive, though not necessarily complete, coverage."

All of the agencies in each region are listed in Appendix A.

A quick glance at Appendix A should convince even the most casual reader that an enormous number of agencies collect water quality data. It also should explain why the OWDC catalog was a primary source of information for this study. Over 350 nonfederal (state and local) agencies are listed, plus all the relevant federal agencies. The writers are confident that no more complete list of such information exists.

The reader should be aware that OWDC does not collect or disperse data. It merely keeps track of who does. The OWDC will supply upon request names and addresses of all the agencies listed as well as a personal contact and telephone number, if known. This was invaluable for the present study.

TABLE 1. OWDC REGIONS AND NUMBER OF AGENCIES COLLECTING WATER QUALITY DATA

No.	Region	Federal agencies	Non-federal agencies	Canadian agencies
1	New England	8	5	2
2	Mid-Atlantic	10	14	2
3	South Atlantic-Gulf	10	32	0
4	Great Lakes	10	15	2
5	Ohio	9	19	0
6	Tennessee	6	13	0
7	Upper Mississippi	7	31	0
8	Lower Mississippi	7	21	0
9	Souris-Red-Rainy	5	9	2
10	Missouri Basin	9	36	2
11	Arkansas-White-Red	8	17	0
12	Texas-Gulf	7	2	0
13	Rio Grande	7	2	0
14	Upper Colorado	6	6	0
15	Lower Colorado	9	9	0
16	Great Basin	10	14	0
17	Pacific Northwest	14	28	2
18	California	13	61	0
19	Alaska	9	4	1
20	Hawaii and other Pacific islands	6	10	0
21	Caribbean	4	1	0

One unfortunate idiosyncrasy of the OWDC catalogs is that the information is not stored in computer data banks. In order to locate the continuous monitors, it was necessary to go through all 21 volumes one page at a time and decipher the codes.

National Water Data Exchange (NAWDEX)

The National Water Data Exchange is also a program of the Department of the Interior. It is administered through the Water Resources Division of the USGS. While OWDC is a cataloging agency, NAWDEX actually deals in data. When fully operational, NAWDEX will be capable of searching the complete USGS water data records as well as the EPA STORET data base. Contact with NAWDEX is established through the Office of the Assistant Chief Hydrologist for Scientific Publications and Data Management at the USGS National Headquarters in Reston, Virginia, Mail Stop 440. At the time of this writing, Mr. George W. Whetstone was in charge of the office. The writers dealt with Mr. Melvin D. Edwards.

At the time the present study was undertaken, the NAWDEX program was only capable of scanning the USGS records. A list of 45 continuous water quality monitors at which flow data were available was obtained. It was subsequently determined that these could have been found in the OWDC catalogs. The advantage of NAWDEX, if there is one, is more current information on the USGS files. Better results, however, can be obtained from the USGS Automatic Data Processing (ADP) Unit, which is described next. The cost of a NAWDEX search is roughly $50 to $100.

USGS Automatic Data Processing Unit

The USGS ADP Unit is located in the National Headquarters in Reston, Virginia. Its purpose is to provide standardized processing programs and procedures for the water resources data collected by USGS. The ADP Unit may be contacted by writing the National Headquarters, Mail Stop 485. Mr. Robert B. Wall is in charge.

This unit is the most up-to-date source of information on the contents of the USGS water quality and flow data base. It is also the place to contact to obtain data in digital format such as cards or magnetic tape. For very reasonable prices ($35 to $70) any of the daily parameter values stored by the ADP Unit can be obtained along with excellent instructions on how to read and translate the cards or tape. The personnel of USGS ADP Unit are some of the most friendly and cooperative of any encountered in the course of this study. The work would have been very difficult without them.

EPA's STORET System

STORET is a computerized water quality data base. It was conceived and initiated in the early 1960s by the U.S. Public Health Service. Its sole purpose is to allow storage and retrieval of water quality information by government users. Contact with STORET is initiated by calling the User Assistance Center in Washington, D.C., at (202) 426-7792. Mr. Phil Lindenstruth was very helpful to this study.

The potential STORET user is in for a difficult time if he does not have connections with a government agency. While anyone can walk into the USGS and receive data for a fee, this is not true of STORET. Some kind of government account number is required. For the purpose of this study it was necessary to obtain a user identification number through the project officer.

Finding continuous monitor records in STORET was not easy. A number of the people at EPA Headquarters were convinced that no more than half a dozen continuous monitor records were in STORET. Over 1100 were eventually located. Approximately 200 of these monitors were located on lakes, over 100 in pipes, almost 100 beside the ocean, and about 50 in intakes and estuaries. This left about 500 monitors located along rivers. Data from all the river sites below urban areas were transferred to a digital tape for use in this study.

The water quality data in STORET is in an unusual format. Daily and hourly observations are mixed together in a continuous string. This complicates processing to some degree. The potential user should be aware that STORET contains no flow information.

U.S. Army Corps of Engineers (COE)

The U.S. Corps of Engineers maintains on its own or through USGS a great many water quality monitors. These are listed for the most part in the OWDC catalog described earlier. Virtually all are located at the inlet or outlet of reservoirs and were of no interest to this study. No direct data input from COE is included here.

State and Local Agencies

Little actual contact was made with state and local agencies during the course of this study. There are two reasons for this. First, the OWDC catalogs are a definitive source of which state and local agencies collect water quality data. The very great percentage of those that do, did not have continuous data bases. They concentrate on random observation. Very few data on flow are available from such sources. Second, those rare state agencies that actually collect continuous data report the data to the Environmental Protection Agency's STORET data base. Thus, it was not necessary to spend a great deal of time contacting many places. Two agencies that do maintain their own data bases are the Wisconsin Department of Natural Resources and the Metropolitan Sanitation District of Greater Chicago. They are described below.

Wisconsin Department of Natural Resources

The Wisconsin Department of Natural Resources maintains a network of 11 water quality monitors. It also records flow continuously. The WDNR may be contacted at Box 7921, Madison, Wisconsin. Mr. Mitchell S. Nussbaum of the Water Quality Evaluation Section was quite helpful.

For a very reasonable amount, the WDNR will copy all 11 stations of daily data onto a magnetic tape. Hourly data are also available. The WDNR is as helpful and courteous to deal with as the USGS ADP Unit.

Metropolitan Sanitary District of Greater Chicago

The Chicago Sanitation District maintains a number of flow-water quality monitor stations in and around Chicago. Many are located in canals. Hourly data are available, but in digital forms. Hand-copying of the numbers in person at its offices in Chicago is the only way to obtain information. Even this can only be arranged with difficulty. A letter from a government project officer explaining the need for the data is required. Because of the manpower and travel requirements, no data were used from this source in this study.

At the time of this writing, the point of contact is Dr. Cecil Lue Hing, Director of Research and Development, Metropolitan Sanitation District of Greater Chicago, 100 E. Erie Street, Chicago, Illinois, 60611.

Ohio River Valley Water Sanitation Commission

The ORSANCO is an interstate compact agency. It was created in 1948 by the states bordering the Ohio River. Its primary purpose is to monitor and prevent pollution along the river. To achieve this, ORSANCO maintains a network of water quality monitors. This network reports continuously to the headquarters in Cincinnati, Ohio, where a complete picture of the quality of the river at any time is available. The address of the commission is 414 Walnut Street, Cincinnati, Ohio, 45202.

At various times, 56 monitor sites have been placed on the river. Half of these have been in continuous operation since 1961; the DO and temperature data from these stations are available on an hourly basis. However, no flow data are available. For less than $100, ORSANCO will copy all the data onto a digital tape.

While the data are readily available, there are serious drawbacks. Most important is the data format. Because of ORSANCO's interest in an "overall" look at the basin, the numbers are not grouped by station. Instead, each tape record contains data for one day for all stations reporting that day. The records are random length and structured in such a way that hundreds of tape reads are required to sort the data by station. A second drawback is the age of the ORSANCO tape drives. ORSANCO's system is an IBM 11/30. The tapes it provides produce numerous read errors on later-model IBM equipment. Processing cost was so high for the ORSANCO data that none is included in this report. For example, it cost $45 to transfer three months of a single station to a disk pack and plot the results.

National Climatic Center

Precipitation data for the present study were obtained from the National Climatic Center in Asheville, North Carolina. Its address is Federal Building, Asheville, North Carolina 28801. Telephone inquiries can be made to (704) 258-2850, ext. 683.

The Climatic Center is a data bank for the parent agency, the National Oceanic and Atmospheric Administration (NOAA), which is part of the Department of Commerce. A very large quantity of atmospheric data is available there. Literally thousands of rain gages are scattered at small airports and other locations throughout the United States. Most of these report daily. In addition, it maintains nearly 300 primary weather stations that record rainfall, temperature, wind, and relative humidity on an hourly basis. This voluminous information is available in monthly and annual reports and on digital tapes or cards.

For this study, only two forms of data were used. In the initial phases a digital tape containing daily precipitation and other variables was obtained. This type of data is very costly. For reasons that were never clear to the writers, the Climatic Center charges $33 to mount a tape. An additional charge of roughly $50 per single station is encountered as each station requires a separate tape mount. These charges are very high compared to other government agencies on a per-number basis. They are also much higher than private computer centers. However, the Climatic Center is the only available source. Digital data have a large lead time of six to eight weeks.

The large money requirement ruled out obtaining the hourly data for the later phases of the study in digital form. Instead, free copies of "Local Climatologic Data," a monthly publication, were obtained from the National Weather Service (NWS) in Silver Spring, Maryland. These contain the hourly precipitation for the month of issue. The normal single copy price of the local climatologic data is $0.20. These may be ordered from the National Climatic Center in Asheville.

SITE SELECTION PROCESS

The process of selecting monitors for inclusion in the study was quite time consuming. It consisted of four steps. First, the data bases discussed above were scanned to discover which of the water quality stations were actually continuous monitors. Next, the continuous monitor sites were located. Following location, each monitor was classified as to its usefulness to this study. Finally, those with the best classification ratings were selected and data obtained. Each of these steps will now be described in detail.

Monitor Discovery

The process of discovering monitor data for use in this study was complicated by the number of agencies involved and the variety of cataloging systems. Many of the possible sources of information (exclusive of the large federal groups such as USGS or EPA) were not known to the writers at the outset. It became a matter of detective work to go from known specific monitor listings to more general information.

The first government agency contacted was the Water Resources Division of the USGS. The NAWDEX provided a list that supposedly contained all the continuous USGS water quality monitors where flow was also recorded. There were only 45. Two of the writers had worked for USGS for over 10 years and were aware of monitors that did not appear on the list. Further inquiries led to the Office of Water Data Coordination and individual USGS district offices in the various states.

The Office of Water Data Coordination was the best source of monitor sites discovered in the entire study. Its 21-volume catalog contains thousands of locations where sampling activities occur. There was only one serious drawback. Continuous monitors are not separated out except by letter codes. Each of the several thousand pages could contain from zero to 10 monitors useful to the study. These had to be located by going through the 21-volume one page at a time, reading the codes, and writing down potentially useful sites and the governing agency. This process produced a very comprehensive list of likely sites.

The USGS maintains a district office in almost every state in the union. These offices conduct water quality monitoring through cooperative agreements with many state, local, and other federal agencies. Most monitors are designed to specifications set by the USGS. The writers initially set out to call all 50 district offices one by one to determine if monitors were available that did not appear on the NAWDEX list. Inquiries were also made concerning activities in the cooperative program. During this slow process, several districts suggested contacting the USGS ADP Unit and obtaining a list of the monitors on the backfile records. This provided a list of all water quality monitors maintained by USGS as well as flow stations. The list was far more comprehensive and up to date than the one obtained from NAWDEX. No further searches were conducted for USGS monitors.

No difficulty was encountered in determining how many monitors were available from ORSANCO or EPA. ORSANCO merely provided a comprehensive list. Cross-checks verified that the same information was available through the OWDC catalogs. At first, it was difficult to gain access to the STORET system. Once a user number was obtained, very little time was required to obtain lists of the monitors contained in the data base. A great many of these were state and local agency monitors that were also listed in the OWDC catalogs.

In all, over 1500 monitors that recorded continuous DO and temperature plus other parameters were located. The next steps were to locate, classify, and sort them to determine which were near urban areas and had flow and rainfall data available.

The location, classification, and sorting processes are described in the following sections. Each of the 1500 monitors was processed in the same way unless it became obvious for some reason that it did not apply to the study (for instance, a monitor 50 miles from the nearest town in the middle of a swamp).

Monitor Site Location

Most monitors were located by means of latitude and longitude coordinates. All the station lists with the exception of ORSANCO reported an accurate latitude and longitude for each site. ORSANCO locates its stations by COE river mile markers.

In the early parts of the study, USGS 7.5-minute topographic sheets were purchased and used to locate monitors and flow gages. This proved unwieldy and expensive. To avoid buying so many maps, most locating was done at the National Headquarters Library of the USGS. Topographic maps covering 7.5 minutes, 15 minutes, and at a scale of 1:250,000 for the entire country are available there. Each monitor was found and its proximity to an urban area noted. As mentioned in the previous section, a number of monitors were rejected from consideraton at this point if no urban area was in a position to affect the stream.

Locating the monitors on 7.5-minute quadrangles required one intermediate step. The appropriate quad sheet name had to be determined. This was done by obtaining index sheets for all 50 states from the USGS Cartographic Information Center at the National Headquarters in Reston, Virginia. These were free. Where possible, the town after which the monitor was named was located and the quad sheet identified. If the town could not be found, rough latitude-longitude was used and several quad sheets picked. The quad sheet names and other pertinent information were entered on a classification form, which will be discussed shortly. The format is presented in TABLE 2.

Monitor Site Classification

Classification of the monitor sites for suitability was an important step. Several factors had to be considered. These were

- proximity to urban drainage area,
- presence of continuous record,
- length of record,
- proximity of flow gage,
- proximity of rain gage, and
- length of time monitor was in operation.

There were several hundred monitors to consider, which made it impossible to remember even a small portion. The previously mentioned standard classification sheet was developed and filled out at the time the monitors were being located. An example of the completed form is shown in TABLE 2. Although the form indicates that it was used only for monitors in the OWDC catalog, it was actually used for all monitors in the study. A complete list of slightly over 100 monitors considered for analysis is contained in Appendix B.

The state column was used to identify both the state in which the monitor was located and the 7.5-minute quad sheet required to locate it precisely. The station name, agency, latitude, and longitude columns are self-explanatory. The site column identified the type of monitor location. These were based on the OWDC catalog description or the writer's observation of the topographic map. The date established is self-explanatory. This information came from either the OWDC catalog or the agency that operated the station. The column labeled water discharge indicates whether or not a stream gage was located near the monitor. Information obtained in this regard was occasionally misleading. The USGS, for example, assigns different

TABLE 2. LIST OF ALL SITES CONSIDERED FOR DAILY OR HOURLY ANALYSIS

State	Station name	Agency*	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
Alabama	Coosa R. at Verbena	GS	324756	862602	Stream	1974	Yes	Montgomery	–	4
	Coosa R. at Gadsen	EPA	340057	855843	Stream	1971	Yes	Gadsen	–	4
Colorado	S. Platte R., 60 ave.	EPA	394826	1045730	Stream	1968	Yes	Denver	<10	1
	S. Platte R., 88 ave.	EPA	395115	1045615	Stream	1968	Yes	Denver	<10	1
	Burlington Ditch at York St.	EPA	394802	1045730	Canal	1967	Yes	Denver	<10	1
	Sand Cr. at Burlington Ditch	EPA	394837	1045659	Stream	1967	Yes	Denver	<10	
Georgia	Chattahoochee R. at Atlanta	EPA	335132	842716	Stream	1960	Yes	Atlanta	10	1
	Peachtree Cr. near Atlanta†	GS	335133	842716	Stream	–	No	Atlanta	10	1
	Ocmulgee R. near Warner-Robins†	GS	324017	833611	Stream	1970	No	Macon	20	4
Illinois	Calumet R. STW†	G01	413946	873940	Canal	1969	No	Chicago	20	2
	Chicago R. Bridge†	G01	415333	873832	Stream	1969	Yes	Chicago	5	1
	Chicago Sanitation and Ship Canal at Lockport†	G01	413408	880441	Canal	1969	Yes	Chicago	35	2
Louisiana	Bayou Tech at Olivier	GS	295718	914254	Stream	1972	Yes	–	–	–
	Houma Nav. Canal near Dulac†	GS	292306	904347	Stream	1973	No	–	–	–
	Ouachita R. at Monroe	GS	323019	920732	Stream	1954	Yes	Shreveport	90	4

*The agency codes, taken from OWDC, identify the agency that was in charge of the data ; specifically, GS = Geological Survey, EPA = Environmental Protection Agency, and GO1 = Metropolitan Sanitation District of Greater Chicago.

†Site was later dropped.

names and station numbers to monitors and gages that are not exactly in the same place, even if only a few hundred yards separates them. Thus, the monitor Lonely River at Outback, Montana, may be listed by OWDC or the USGS as having no flow. A stream gage named Lonely River near or below Outback, Montana, may be quite nearby. This problem was minimized by checking USGS state reports to determine if what OWDC indicated was true. The rain column gives the location of and distance to the nearest weather bureau primary weather station (those with hourly rainfall data). The distances are in miles. The last column, applicability to study codes, was used to rate each site as to its usefulness to this research. These ratings tended to be subjective and based heavily on how the monitor's location on the map appeared in relation to an urban area.

The classification codes are listed in TABLE 3. The amount of urban area was judged by eye. In general, towns were judged in relation to the size of the river. A town of 1/4 square mile on the Mississippi was ignored. The same town on a small river was included. Thus, the terms "significant urban area" and "small town" were relative rather than absolute measures. The criterion of 15 miles to a weather station was based on judgment and experience with other studies.

TABLE 3. STUDY CODE CLASSIFICATIONS

Code	Definition
1	Significant urban area, NWS primary station within 15 miles
2	Significant urban area, NWS primary station farther than 15 miles
3	Some urban area, NWS primary station within 15 miles
4	Some urban area, NWS primary station farther than 15 miles
5	Small town(s)
6	No urban area
7 (1-6)	Reservoir or lake

Site Selection

By the time the study had progressed to site selection, it became apparent that there were very few places that met the criteria in the Scope of Work. These criteria were the existence of five years of research including hourly flow, DO, and temperature plus 15-mile proximity to a rain gage with hourly data.

There were 12 in the USGS, none in ORSANCO, none in EPA's STORET, and only a few with other agencies.

A decision was subsequently reached through discussion with the project officer to broaden the Scope of Work. It was decided to accept sites with five years or less of data, to examine sites that had only daily data, and to consider sites that were not near hourly rain gages. At the same time, it was decided to concentrate initially on daily correlations and use the hourly data for a detailed look at sites with strong daily flow-DO deficit correlations.

Summary

A review of the process of site selection is now in order. Initially, slightly more than 40 USGS monitors were found in the NAWDEX system. A search of the OWDC catalog series added 250 more. Several additional USGS monitors were located through the ADP Unit. ORSANCO added 56. A search of the STORET files produced 1100. Thus, there have been nearly 1500 monitor sites established along the nation's streams, lakes, and estuaries. Each monitor was located on USGS maps and evaluated for proximity to urban areas. They were further rated on proximity to rainfall and flow gages and for length of record. Those in proximity to an urban area of significant size and which were near a flow gage or primary weather station were selected for daily correlation analysis. The number of such sites was slightly greater than 100. The process of examining these on a daily basis is the subject of the following section.

Some explanation is in order on why out of 1500 monitors less than 10 percent were considered. The most common reason was that the monitor was not in or near any urban area. The vast majority of EPA's monitors (at least those in the STORET files) are at industrial outfalls or in canals or lakes. This is also true of the USGS and ORSANCO networks. A small minority of monitors were rejected because no flow records were available. Some were rejected because an examination of the daily monitor records indicated no quality problems at any time. Some sites were incorrectly listed as continuous monitors when in fact they were just grab-sample locations.

The list of all monitors considered is too large to conveniently publish here, even as an appendix. Appendix B expands TABLE 2, presenting 104 sites that were seriously considered for analysis. The following section describes how the 104 sites were analyzed. Note that the ORSANCO sites considered for analysis are included even though they were not analyzed because of the awkward data storage format.

SECTION 6

DAILY CORRELATION ANALYSIS

GENERAL CONSIDERATIONS

The necessity for basing initial correlation efforts on daily data stemmed from broadening the Scope of Work to accept monitors with less than five years of data or located more than 15 miles from an hourly rain gage. Hourly data are difficult to obtain and process. For example, hourly data from the USGS are not stored on permanent files in a computer or on magnetic tape. They are available only on listings called primary computation sheets. In order to analyze a year of this type of data, one must read 8760 numbers from the sheets and either punch the values on cards or have them put on tape. Performing hourly correlation analysis on 100 sites with an average of 2.5 years record and four parameters (DO, rainfall, temperature, and stage) would require 8,760,000 numbers.

Another important factor restricts the use of hourly data. Hourly precipitation data are only available at about 300 sites throughout the United States. Therefore, many dissolved oxygen monitors are located at such a distance from these primary weather stations to make an hourly correlation between DO and rainfall meaningless.

The necessity of using daily data to supplement the hourly values was anticipated in the Scope of Work:

> "Some of the available data banks have been summarized and contain only daily average values. These can be utilized to determine whether the particular stream segment should be included in the analysis, but it will be necessary to obtain the hourly parameter variations from the organization responsible for the water quality monitoring or rainfall station in carrying out the analysis."

The method of examining daily data first saved a great deal of computation by allowing use of readily available computer tapes. The USGS, STORET, and WDNR data bases were all able to provide daily values in this form.

There were three distinct phases to the daily correlation analysis. First, the daily data had to be acquired and converted to a standard format. These values were stored on a computer direct-access file. Second, the stored values had to be retrieved and processed with suitable correlation programs. Finally, sites for hourly and detailed analysis were selected. Each phase will be discussed in turn. The computer processing and results of the analysis will be presented first. The process used for selecting sites for hourly analysis completes the section.

PRELIMINARY DATA ACQUISITION PROCESSING

Four major computer programming efforts were required to accomplish the first phase of data processing. Each type of taped data (USGS, NWS, STORET, and WDNR) required different recovery and processing methods. A short discussion ot the data formats and the processing problems encountered with each will now be presented.

USGS Data

The importance of USGS data to this study cannot be overemphasized. When the site selection process was complete, 62 of its monitors were of interest. USGS flow data were often required to supplement DO data from other sources. For these reasons, the USGS data were obtained and processed first.

The USGS ADP Unit is highly cooperative and accustomed to dealing with the public. To request data, all that is required is a letter or memorandum stating what stations and years of record are of interest. In from three days to a week the requested data arrives along with a detailed set of instructions on how to decode it. The price for 100 station-years of record including a magnetic tape is around $65. The appendix of the instruction book contains a program for reading and listing either a data tape or cards. Anyone familiar with programming can have the program operational in less than a day.

The data are stored on tape such that data covering a year are easily accessible at a particular site. The USGS uses water years, which begin October 1 and end on September 30 the following year. The data values are stored in a two-dimensional, 12 x 31 array. This is preceded by header information such as the state code, latitude and longitude, year of record, and other information. Days that do not exist (such as February 31) or missing data are marked by a 999999 no-value indicator. TABLE 4 presents the 9-track 1600 bpi tape format used by the USGS.

The program provided by USGS to read and list the tape was modified slightly to write the 12 x 31 arrays, the station name, the year of record, and the latitude-longitude onto a direct

TABLE 4. USGS, 1,656-BYTE, MAGNETIC-TAPE OUTPUT FORMAT

Byte position	Data type	Description
1–2	CHAR (2)	Blank.
3–4	CHAR (2)	Code for the state in which the station is located.
5–9	CHAR (5)	Code for the agency collecting the data.
10–24	CHAR (15)	Station identification number (right justified).
25–28	FLOAT (6)	Cross-section locator. Location of sampling point in the cross-section. A value of '999999' indicates no value stored.
29–32	FLOAT (6)	Sampling depth. Depth at which sample was collected. A value of '999999' indicates no value stored. A value of '111111' indicates a top sample and '888888' indicates a bottom sample.
33–36	FIXED BIN (31)	Parameter code.
37–38	FIXED BIN (31)	Calendar year date.
39–40	FIXED BIN (15)	Statistic code.
41–44	FLOAT (6)	No value indicator – value that is stored in place of a missing daily value. A value of '999999' is stored as the no value indicator for most data. The no value indicator is also stored for non-existent days in the array, such as February 30.
45–1532	FLOAT (6)	Two-dimensional array (12, 31) containing all of the daily values for a 12-month period. For additional information, see page 12.
1533–1535	CHAR (3)	Blank.
1536–1537	CHAR (2)	Code for the state in which the Geological Survey office that operates the station is located.
1538–1540	CHAR (3)	Code for county in which the station is located.
1541–1588	CHAR (48)	Station name.
1589–1592	FLOAT (6)	Drainage area of the site in square miles. A zero indicates no value stored.
1593–1596	FLOAT (6)	Contributing drainage area of the site in square miles. A zero indicates no value stored.
1597–1600	FLOAT (6)	Depth of well. The greatest depth at which water can enter the well. Applicable only to sites coded as 'GW'. A value of '-99999' indicates no value stored.

(continued)

TABLE 4 (continued).

Byte position	Data type	Description
1601–1604	FIXED DEC (7, 2)	Datum of gage to nearest hundredth of a foot.
1605–1608	FIXED BIN (31)	Hydrologic unit code.
1609–1610	FIXED BIN (15)	Retrieval sequence number for data control of batched retrievals.
1611–1612	FIXED BIN (15)	Month number that contains the beginning date of the 12-month period. For additional information, see page 12.
1613–1614	CHAR (2)	Site code. The codes are: SW = Stream SP = Spring ES = Estuary GW = Well LK = Lake or reservoir ME = Meteorological
1615–1620	CHAR (6)	Latitude of the site location in degrees, minutes and seconds.
1621–1627	CHAR (7)	Longitude of the site location in degrees, minutes and seconds.
1628–1629	CHAR (2)	Sequence number——used differentiate between stations having the same latitude and longitude and to identify the site location in relation to the Earth's spherical quadrants.
1630–1637	CHAR (8)	Geologic unit code.
1638	CHAR (1)	Reserved.
1639	CHAR (1)	Aquifer type. The codes are: U = Unconfined single aquifer. N = Unconfined multiple aquifer. C = Confined single aquifer. M = Confined multiple aquifer. X = Mixed (confined and unconfined) multiple aquifers.
1640–1656	CHAR (9)	Blank.

Source: "Data Formats for U.S. Geological Survey Computer Files Containing Daily Values for Water Parameters," by Charles R. Showen, 1976.

access disk file. This allowed any year at any station to be called into the computer without reading any others. Because of the relatively large number of USGS monitors that were to be analyzed and because of the convenience of the 12 x 31 array data format, daily data from other agencies was converted to this form. By building the disk files in a single format, only one set of plotting and analysis programs will be discussed following the presentation of the data formats of the other agencies.

Data are stored in the Daily Values File as a data array that comprises a water year of data (October 1 through September 30). The water-year date is designated by the calendar year in which the 12-month period ends. The daily values data array is always represented as a two-dimensional array (12,31), with the month as the first dimension and the day as the second dimension. The data are physically stored in the array such that the first data value (01,01) is for January 1, the second data value (01, 02) is for January 2, etc., on through December 31 (12,31).

The data within each daily values array may be chronologically ordered for output to comprise any type of year. However, the physical order will always begin with the values for January and end with those for December even though two calendar years are spanned. The type of year stored within a daily values record is defined by a beginning month number stored in the record. Unless specifically requested, the daily values output records will be comprised of water years (beginning month = 10). For example, data for the 1974 water year are physically stored in the data array such that the first data value (01,01) would be for January 1, 1974, the 180th data value (10,01) would be the data value for October 1, 1973, and the data value in the array (12,31) would be for December 31, 1973.

In terms of number of monitors the STORET data base was second to USGS. The monitor records were from a variety of federal, state, and local agencies. The STORET data were some of the last to be processed because of the difficulty in gaining access to the system for private organizations. Once in, however, the system works well.

The personnel of the STORET user assistance facility at EPA Headquarters in Washington, D.C., created a number of useful products for this study. First, a scan was done on the data base to produce a list of all the continuous water quality monitors. This was mentioned previously, in the site location section. After this listing had been evaluated and the monitors of interest selected, all the daily and hourly data available at each monitor were transferred to a magnetic tape.

STORET intermixes daily, hourly, and random observations. This makes processing more difficult. STORET, as with USGS, provides the user with a sample reading and translation program. The only difficulty with it was sorting out what variable went with what variable name. This was necessary to know so that useless data could be discarded. Roughly one week of effort was required to get a working program.

The data came in a format somewhat similar to the USGS but not in 12 x 31 yearly arrays (TABLE 5). The sequence of records (Delimiter-station-data) shown in TABLE 5 is repeated until all stations retrieved have been exhausted. An IBM "end-of-file" is encountered following the last data record. FORTRAN programmers must code an "END-" control transfer in the read statement for the data records to avoid a program interrupt at end-of-file.

The data were read from the tape, sorted, restructured, and then written on the disk file in 12 x 31 water-year arrays. The initial cost of the data is unknown since it was supplied by EPA. Processing costs were moderate, that is, $200-300.

National Climatic Center (U.S. Weather Bureau) Data

Daily precipitation data used in the study came from the National Climatic Center. Daily precipitation data are available for many locations in the United States and almost all DO monitors were located within a few miles of these stations. However, only about 300 hourly precipitation stations are available and many water quality monitors are too far away from precipitation stations to make hourly analysis meaningful.

The daily precipitation data are readily obtained from the National Climatic Center, but as mentioned earlier, they are very expensive. The numbers are stored on the tape as computer card images. A standard computer card has 80 columns in which numbers and symbols can be punched. The same format is used on tape and is given in a publication from the U.S. Weather Bureau (1009 Daily Observations 486). The card image and column-by-column description are presented in Figure 1 and TABLE 6, respectively. Only the first 33 columns are shown in Figure 1 since these are the ones used in this study.

WDNR Data

The WDNR is one of the few state agencies that collects and stores its own DO data instead of reporting them to STORET. This data source was found in the OWDC catalogs. Daily data from 11 stations were ordered for the years 1972-1977. The data were similar in format to the U.S. Weather Bureau data. Station identification, date, DO level, water temperature, and flow were

TABLE 5. RECORD ARRANGEMENT ON DISK FILE FOR STORET MORE=4*

Group	Description
1	Parameter heading records. Each record is 145 characters long. The first 25 characters of each record may be ignored. The remaining 120 characters are a printable alphanumeric line. These lines, in groups of four, would comprise the columns printed by the standard retrieval. With MORE=4, there will be five groups of four lines each, a total of 20 parameter heading records.
2	Dummy data record. This is a delimiter record in Group 4 format, containing the print characters '99' in columns 26 and 27.
3	Station heading records. Each record is 145 characters long. The agency code is in column 1-8, the station code is in column 9-23. Column 24 is blank. Column 25 contains a line number (1 through 9, in order). The remaining 120 columns of each record are a printable alphanumeric line. There are nine such records in this group. These nine lines are normally printed at the top of each page of retrieval output. The content is affected by use of the "SHIFT" and "HEAD" parameters in the retrieval deck.
4	Data records. Each record covers one sample, either grab or composite, and its remarks codes. Each record is 305 characters long. Agency code is in columns 1-8, station code is in columns 9-23, columns 24 and 25 contain '99', columns 26-31 contain the date as YYMMDD, columns 32-35 contain the time (0000-2400, with blank time stored as 2500). The next 200 columns (36-235) contain the values of the water quality parameters retrieved, in IBM four-byte words. The FORTRAN programmer must read this field as 50 A4, into an array whose type is REAL-*4. Missing entries in this field, which occur either when fewer than 50 parameters are retrieved or when no data were stored for a particular parameter within the sample, are key-coded with a binary number approximately equal to 1.E-20. The next 50 columns (236-285) contain the STORET alphabetic remarks codes to go with the parameters retrieved. Column 286 will be blank if this represents a grab sample, and the next four columns may be ignored. If this is a composite sample, column 286 will contain "S", "T", or "B" for space, time, or both. Column 287 will be coded "A" for average, "L" for minimum, "H" for maximum. Columns 288-293 contain a date in the form YYMMDD. This will be an initial date for comprehensive composite samples, and a final date for a regular composite. Columns 294-297 are time for the same point (0000-2400). Columns 298-299 are the number of samples comprising the composite. Columns 300-340 are sample depth, and column 305 is coded "B" to indicate bottom sample, and is otherwise blank.
5	Delimiter data record with year coded '99' in date area (columns 26-27).
6	Station heading records for next station, formatted as in Group 3.
7	Data records - See Group 4.

*This is the broadest type of retrieval possible, allowing for as many as 50 parameters and more than one station.

Source: STORET Handbook Supplementary Manual, Volume 2, "Advanced Retrieval."

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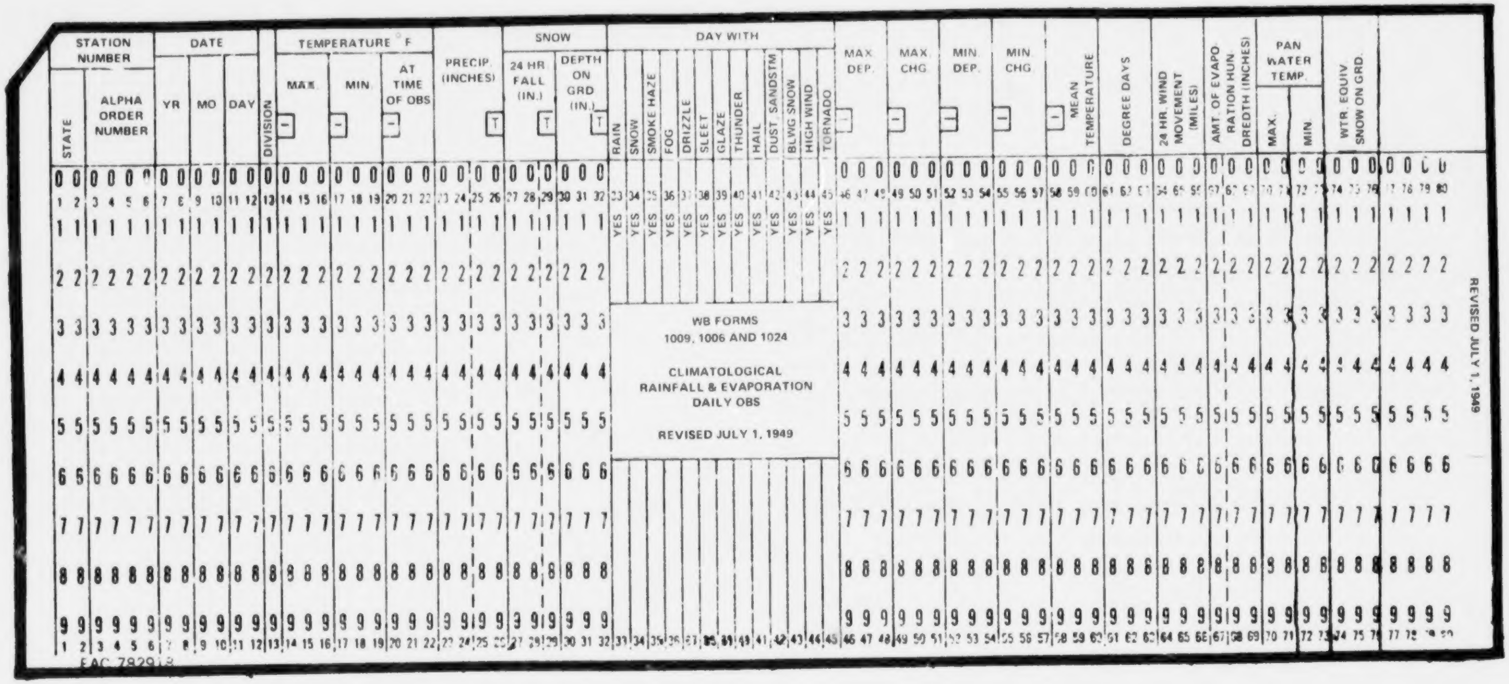


Figure 1. Card format used by National Climatic Center for weather data.

TABLE 6. CARD IMAGE CONTENT FOR NATIONAL CLIMATIC CENTER WEATHER DATA

Column	Item or element	Symbolic letter	Card code	Card code definition	Remarks
1-33 35-76	Missing data		B X/	Blank X overpunch	Columns blank if data missing or not reported. See supplemental card content for 1949 and prior years, page 5.
1-2	State index number		1-99	State index number	Assigned alphabetically. See list on page 6, maps pages 2 and 3.
3-6	Station index number		0001-9999	Station index number within state	Number assigned in proportion to its relative position in "Index of Cities and Towns" in Rand McNally Atlas, 65th edition.
7-8	Year		00-99	Last 2 digits of year	80-99 for 1880-1899.
9-10	Month		01-12	January to December	
11-12	Day		01-31		
13	Intrastate-division and time of observation		0-9	Climate Division within state 0 = 10	Indicates division number with p.m. observation.
			X/	X overpunch for a.m. observations	Indicates division number with a.m. observations. X overpunch for a.m. observations discontinued 1 July 1967.
14-16	Maximum temperature	$T_xT_xT_x$	000-199	Whole degrees F	For 24 hours ending at time of observations.
			X01-X99	X punch in column 14 indicates minus (-)	Note: When temperature was rounded to whole degrees (-0.4° F rounded = 0° F punched 000) (-0.5 = -1° F punched X01).
			X/	X overpunch in column 16 indicates estimated maximum temperature	
17-19	Minimum temperature	$T_nT_nT_n$	000-099	Whole degrees F	For 24 hours ending at time of observations.
			X01-X99	X punch in column 17 indicates minus (-)	See note columns 14-16.

(continued)

TABLE 6 (continued).

Column	Item or element	Symbolic letter	Card code	Card code definition	Remarks
17-19 (continued)			X/	X overpunch in column 19 indicates estimated minimum temperature	
20-22	Temperature at observation time	TTT	000-199	Whole degrees F 0 in column 20 = + value	See note columns 14-16.
			X01-X99	X punch in column 20 indicates minus (-)	
23-26	Precipitation	RRRR	0001-9999	00.01-99.99 inches to hundredths	For 24 hours ending at time of observation.
			000X	Trace	Less than 0.005 inches.
			XBBB	None, X in column 23	Blank in columns 24-26. Some stations use 0000 for none.
			00XB	Amount included in subsequent measurement	Blank in column 26.
			X/	X overpunch in column 24 indicates accumulated value	
					Note: Beginning Dec. 56 estimates of daily precipitation were derived from snowfall by the 10 to 1 ratio method and identified by "X over 9" punch in column 33. However, state climatologists have been authorized to use X/9 punches in column 33 to indicate estimates of daily precipitation derived by other methods.
27-29	Snowfall includes sleet	sss	001-999	00.1-99.9 inches to tenths	Amount for 24 hours ending at observation time.
			XBB	X in column 27 no snowfall	Note: Hail included with snowfall from July 1948 - December 1955. Hail

(continued)

TABLE 6 (continued).

Column	Item or element	Symbolic letter	Card code	Card code definition	Remarks
27-29 (continued)			OXB	0 in column 27, X in column 28 amount included in subsequent measurement	occurring alone was not included with snowfall and snow on ground before and after that period.
			00X	Trace	Less than .05 inch.
			X/	X overpunch in column 28 for 100.0-199.9	
30-32	Snow depth on ground includes sleet and ice	sss	001-999	1-999 inches (whole inches)	Depth of snow at time of observation . See Note Columns 27-29.
			00X	Trace	Depth of less than 0.5 punched as trace.
			XXB	X in column 30 = none	Blank in columns 31-32.
33	Estimated precipitation		X/9	When precipitation amount in columns 23-26 estimated from snowfall by the 10 to 1 ratio	Columns 33 and 34 not punched for "day with," effective 1 January 1949. See note columns 23-26 above.

in specified locations on the tape. The data were written in ASCII characters, which were converted to integers and then to floating point numbers as was the Weather Bureau data. These were again stored on the permanent file in 12 x 31 water-year arrays.

The tapes of data from WDNR were obtained at a reasonable cost of about $60. Processing was similar to that of the Weather Bureau.

ORSANCO Data

Data from ORSANCO were not used in this study primarily because of difficulties related to the way it is stored for computer processing and secondarily because the Ohio is a large river and few of the urban areas along it have drainage areas significant to that of the river itself. This section is included because other investigators may wish to examine ORSANCO data. The data format and the difficulties it causes are described here.

Two magnetic tapes of data were obtained from ORSANCO. The first tape contained the ORSANCO robot monitor data for 1961 through 1974. The second tape covered 1975 to July 31, 1977. This includes hourly data from 28 of the 56 sites it had operated since beginning operation. The data were stored on tape such that all stations reporting data on a particular day were stored in one block. The next block would then contain all hourly data at all stations for the next day. This is a convenient and efficient method of storing data if one wished to see the water quality of the Ohio River basin on a day-by-day basis. However, it is very cumbersome to obtain data on a particular site for a year. A typical data block is presented in TABLE 7. The structure of the data tapes is described in Exhibit 1.

In TABLE 7, words 1 through 10 constitute the block header and the last word of the block is its word count. These are always present and in some cases represent the entire block. This happens when no stations transmitted data for a day. Therefore, block sizes of 11 words should be ignored.

This example illustrates a day (block) when only two stations transmitted data. Each station requires 240 contiguous words (station segment), which are subdivided into 24 groups of 10 words reflecting 24 hours of data each day. Each word in a group has a fixed definition only its value may change. This example shows the first station segment occupying words 11 through 250 with the second station segment at words 251 through 490.

TABLE 7. DATA BLOCK STRUCTURE, ORSANCO DATA

Word	Meaning - one word integers 1 & 2
1	Block number (day of year)
2	Type of block (always equals three)
3	Year of record
4	Month
5	Day of month
6	Storage date - day of year
7	Storage date - year
8	Number of words in this block
9	Zero
10	Zero
11	Station number (first station segment)
12	Hour
13	Test signals
14	Oxidation reduction potential
15	Temperature
16	Conductivity
17	pH
18	Solar radiation intensity
19	Dissolved oxygen
20	Chloride
21	Station number (same value as at word 11)
250	Chloride
251	Station number (second station segment)
252	Hour
253	Test signal
254	Oxidation reduction potential
255	Temperature
256	Conductivity
257	pH
258	Solar radiation intensity
259	Dissolved oxygen
260	Chloride
261	Station number (same value as at word 251)
490	Chloride
491	Number of words in this block

Exhibit 1. Tape file structure description, ORSANCO data.

Each block within a tape file constitutes one day of data for all stations having transmitted data on this day. Each file contains as many blocks as there are days in the year (either 365 or 366).

Blocks are variable length ranging from 11 words (no stations transmitted - just block header) to a maximum of 6731 words (28 stations max.).

Block size is determined as follows:

SIZE = Header + (Numst * Segment) + Word Count,

where

Header = first 10 words of the block and are always present,

Numst = the number of stations that transmitted data on this day,

Segment = 240 contiguous words required to house a station-day (24 hours at 10 words per hour), and

Word Count = the last word of a block, containing the value of 'SIZE'. This word is always present.

ORSANCO IBM 1130 magnetic tape routines write data by calculating the lowest physical core address of the block to be transmitted. Data are written into tape as a single block. The contents of the lowest physical location are written first, with bits 0-7 becoming the first byte on the tape and bits 8-15 becoming the second byte. Succeeding 16-bit words are transferred in a similar fashion.

IBM 1130 arrays are arranged in core storage in descending storage addresses. Element 1 of a five-element array will be at storage address 508 and element 5 at byte 500. This is the reverse of 360 and 370 allocation and results in element 5 being the first element transmitted to tape. Reading these data to an IBM 360 or 370 array requires that the array be reversed in storage.

Thus, unusual structure of the tape required the following manipulation to recover data at a single station:

- initiate a read, which picked up the number of words in a tape block;
- backspace the tape;

- read the entire data block;
- search the input data buffer from the highest element down (remember they are stored backwards) to discover the station of interest;
- transfer 24 values (one day per block) to a storage array;
- translate the 24 values from ASCII to floating point; and
- read the next block.

Backspacing is very inefficient, as are the formatted reads that were required to recover the binary data. The ORSANCO tape drives are old and did not produce a "clean" copy. Many tape read errors were encountered. The cost of transferring three months of hourly data to the disk pack for a single station was $45. Simply figuring out how to read the tape cost over $600. No one at ORSANCO could provide much guidance. Apparently, the people who work the tape software have gone on to other jobs. The people currently on board just use it and did not fully understand it.

The quality of the data on the tape appeared very poor. No flow information was available. For these reasons, the ORSANCO data were abandoned.

This completes the discussion of the computer processing necessary to transfer data from the various agencies to the disk pack for use in the correlation analysis. The following section describes the actual correlation programs and their development.

Data Retrieval and Correlation

The first step in the daily correlation analysis after the required data were stored was to develop a suitable correlation technique. This is not as straight forward as it might seem.

The objective of the correlation program development was to build a program that was a sensitive indicator of the problem in question. That is, it should give a strong numerical indication whenever a site was found where the DO level dropped with increasing flow. At the same time, it should not be costly to run or difficult to implement. These goals were never entirely achieved, but workable methods were obtained with experimentation.

Before undertaking program development, several test data bases were created for Sutron's desktop calculator system.

These test data consisted of a year's daily rainfall, temperature, and DO data from Wilson Creek near Springfield, Missouri. Wilson Creek was selected as a standard because a very well documented problem existed there. Over 80 percent of the Wilson Creek drainage is from Springfield, Missouri. If a correlation program could not clearly identify the problem there, it could not be expected to work elsewhere.

The type of data typical of daily analysis is illustrated in Figure 2. Illustrated are the flow and DO signals. They have been plotted to illustrate the rather obvious correlation of high flow and low DO at Wilson Creek. The problem was to detect this mathematically.

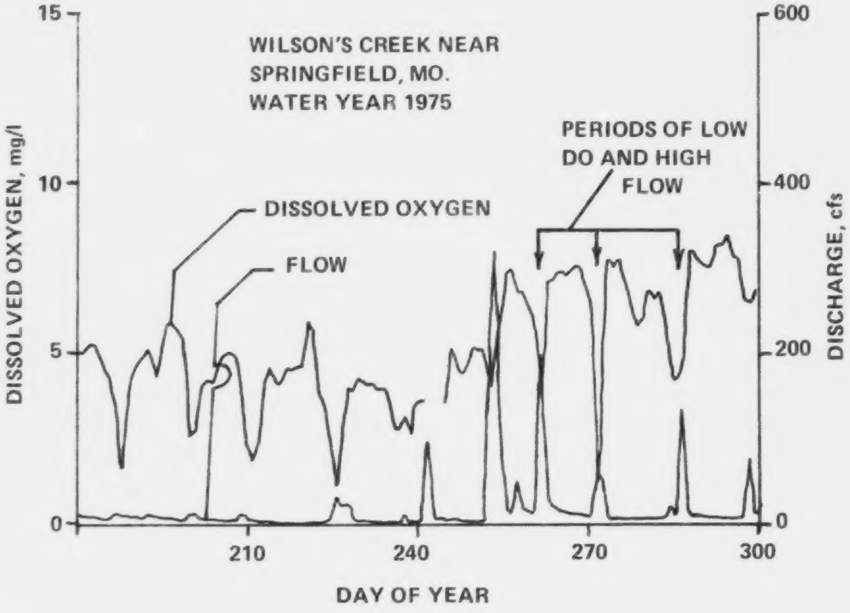


Figure 2. Typical daily flow and DO records illustrating high degree of correlation between high flow and low DO

The first and most obvious correlation method attempted was standard statistical cross-correlation analysis. This is described in several textbooks such as Bendat and Piersol (8). Initially developed in the communications industry, cross-correlation is a means of determining how two such signals "look alike" at different time offsets. A cross-correlation of 1.0 (for properly prepared signals) at zero time lag indicates perfect correlation or identical values at all times. A correlation of zero would mean no relationship. A correlation of 1.0 at an offset of five hours would mean identical signals displaced in time.

Cross-correlation proved unworkable for daily data. The DO signal is more or less random in time with some long-term (low frequency) components. The flow is an intermittent highly skewed signal. Low correlations (0.6 or less) were obtained at all reasonable time lags for the Wilson Creek data. This indicated that other methods must be developed.

The next correlation method used was based on a comparison of the DO levels on "wet" and "dry" days. Various definitions of "wet" and "dry" were tried with both rainfall and flow data. The different definitions of "wet" and "dry" are described as follows. When correlating the DO sag with rainfall, a dry day was when the daily precipitation was zero and a wet day was a day with rainfall greater than zero. When correlating the DO sag with flow, a dry day was when the discharge was less than a given percentage of mean annual discharge and a wet day was when the discharge was greater than the same percentage of mean annual discharge. The percentage was varied from 50 percent to 400 percent by 50 percent increments in order to determine the effect of the wet/dry cutoff. A wet/dry cutoff equal to the mean annual discharge was found to be a reasonable value.

The method was implemented on one year of data at a time. First, all the DO deficits were summed for wet days and for dry days. DO deficit is the difference between the actual DO level and the saturation DO level for a given water temperature. The number of wet and dry days was also computed. The average dry DO sag was then calculated by dividing the sum of all dry DO sags by the number of dry days, and vice versa. The average annual wet DO sag was then divided by the average annual dry DO sag. If this ratio was greater than one, the DO sag was worse during wet weather. This method proved sufficiently sensitive to indicate a problem at Wilsons Creek and was retained for use in the analysis. It was not considered the best method, however.

The final, and most sensitive correlation measure was developed by viewing the occurrence of a correlation in a probabilistic sense. The following questions were asked: (1) "Is it more likely for the DO deficit to increase or decrease when the flow changes or a rainfall event occurs?" (2) "How does this likelihood compare during periods of low and high flow?" The answers to these questions were found by developing a computer counting scheme. Figure 3 illustrates what may be thought of as a four-compartment box. The compartments are labeled A through D. Numbers are assigned to the four compartments by graphing DO deficit divided by a moving average deficit versus discharge divided by average discharge. The averaging period was initially not specified and various values were tried in order to find one

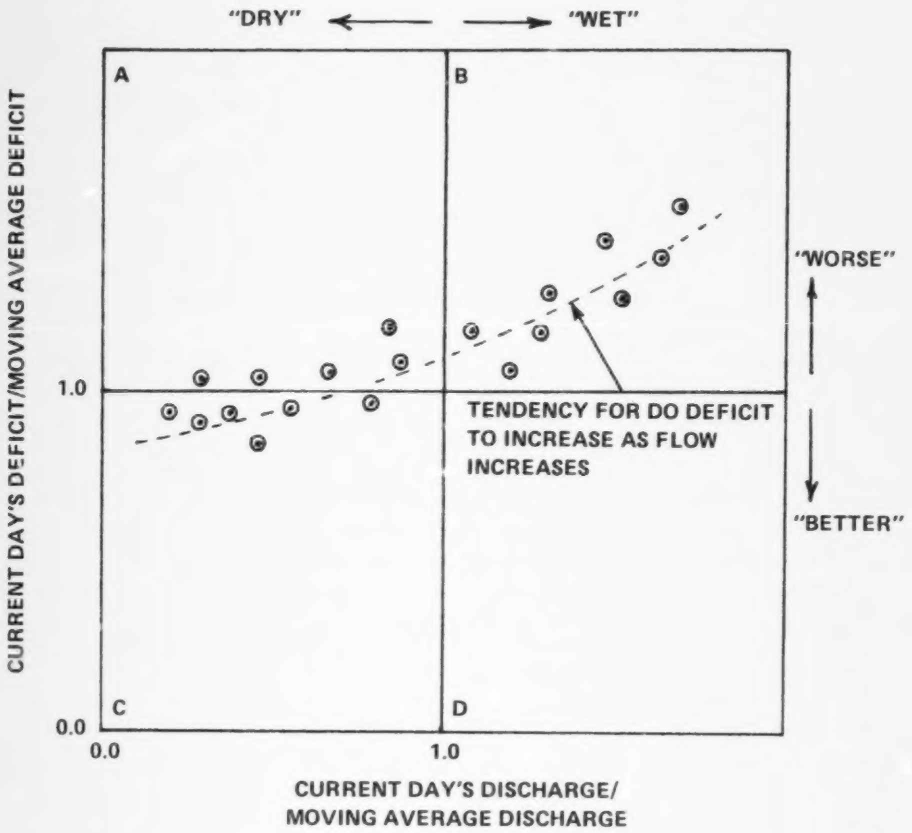


Figure 3. Box or compartment method used to analyze daily data for correlation between high flow and low DO.

most suited to this study. The value of seven days was ultimately chosen as the best.

The reasoning behind the graph is as follows. First, some means was necessary to determine whether the DO deficit on any given day was "better" or "worse" than on previous days. The method selected compares the value observed "today" with the average of the values which occurred for the previous seven days. Thus, a value of (deficit/moving average deficit) greater than 1.0 indicates "worse" and a value less than 1.0 indicates "better." Points on Figure 3 that lie in the upper half (compartments A&B) represent days when the water quality was worse than it had been for the previous seven days. Points that lie below the line (compartments C&D) represent days on which the water quality improved.

Next, some means was required to determine if the water quality consistently decreased on days with rainfall or increased flow. Identifying days with rainfall was easy. Identifying days with increased flow was again done by moving average. The average daily flow "today" was compared with the average for the previous seven days. A value of (flow/moving average flow) greater than 1.0 indicates "increased" flow or "wet" and a value less than 1.0 indicates "decreased" flow or "dry." Points on Figure 3 that lie to the left of center (compartments A&C) represent days on which the flow decreased. Points that lie to the right of center (compartments B&D) represent days with increases.

The logic of Figure 3 can now be discussed. For any year of DO and flow or rainfall data up to 358 points (365 - 7 used for moving average) could be plotted on a graph. By counting the number of points which fell in each of the four compartments it was possible to compare the number of days when DO levels decreased and flow increased (or rain fell) (compartment B) with the number of days when DO levels increased and flow increased (compartment D). If the contents of compartment B were significantly greater than the contents of compartment D, then a correlation was considered to be established between flow (or rainfall) and decreased DO. A number of other comparisons can also be made. These will be discussed later.

The implementation of the probability method was as follows. First, a year of data was retrieved from the disk file. Next, the seven-day moving average was computed beginning with the first days data. The eighth day was then examined to see if the flow had increased or decreased compared to the average of the last seven days and whether the DO deficit increased or decreased compared to the average for the last seven days. The answer gave a point on the graph in Figure 3. The procedure was then repeated with a new moving average beginning at the second day. The number of points that fell in each quadrant of the graph (that is, the compartments of the box) were counted as the process was repeated. At the same time, the strength of the DO deficit in each quadrant (compartment) was computed and summed. This was used to determine how strong the deficits were under high- and low-flow conditions. This was important because even if a correlation between flow/rainfall and low DO existed, a problem did not exist if the DO level did not fall significantly below saturation. At the end of a year's data the number of days in each of the following categories could be obtained by counting the contents of the four compartments:

- wet days with worse than average deficit, compartment B;

- wet days with better than average deficit, compartment D;

- dry days with worse than average deficit, compartment C;
- dry days with better than average deficit, compartment A;
- wet days with worse than average DO, compartment B, using DO values in moving average instead of DO deficit values;
- wet days with better than average DO, compartment D, using DO values in moving average instead of DO deficit values;
- dry days with worse than average DO, compartment C, using DO values in moving average instead of DO deficit values; and
- dry days with better than average DO, compartment A, using DO values in moving average instead of DO deficit values.

The probability of a worse-than-average deficit during wet weather was determined by dividing the number of days of worse-than-average deficit during wet weather by the total number of wet days. Similarly, the probability of a worse-than-average deficit during dry weather was determined by dividing the number of days of worse-than-average deficit during dry weather by the total number of dry days. In these calculations, wet weather is increased flow or day with rain and dry weather is decreased flow or day with no rain.

These two probabilities were compared to see if a worse-than-average DO sag is more likely during wet (day with rain or higher average flow) or dry weather. Similar probabilities were also computed for the DO level itself. The average deficit and percentage of saturation DO level was computed for each of the possible situations. From this, the relative strength of the sag during wet (day with rain or higher than average flow) and dry weather and the relative percentage saturation level of DO could be determined.

The probability method was tested on data from Wilsons Creek near Springfield, Missouri. The method was sensitive enough to indicate the known correlation at that site. A greater than 70 percent probability of low DO at times of higher than average (seven-day moving) flow and on days with rainfall was found for several years of data.

After determining that the probability method would identify a site with a known correlation between flow or rainfall events and DO deficit, it was necessary to set criteria for selecting sites for more-detailed examination. Many sites exhibited correlation between low flow and DO deficit as well as high flow and DO deficit. Only those sites at which low DO could clearly be identified with high flow were desired.

A cutoff level of 60 percent was finally selected. That is, only sites at which the probability of a greater than seven-day moving average DO deficit at times of greater than seven-day moving average flow were chosen for further study. In an independent review of this report, Meta Systems of Cambridge, Massachusetts, verified the 60 percent cutoff level as being statistically valid. A Chi-squared test was used to demonstrate that a probability of greater than 60 percent or less than 40 percent is required in order for nonrandom distributions to exist between two categories at the 95 percent confidence level. Thus, for a given station year if a 60 percent probability of low DO exists at times of high flow or on days with rainfall, then low DO is significantly associated with these events.

Consideration was also given to the absolute DO level in selecting sites. Even though a correlation existed between low DO and flow or rainfall, a "problem" did not necessarily exist. In general, sites were selected where DO levels less than 75 percent of saturation were present at times of high flow.

Results of Daily Correlation Analysis

Presentation of the results of the daily analysis is complicated by the volume of numbers involved. As mentioned in the previous section on Site Selection, the potential locations to be analyzed was 104. Three primary factors reduced the number to 83. First, data could not be obtained for some sites. Second, information in the OWDC catalog was not always accurate. Finally, the list of 104 sites included a number of ORSANCO monitors that were not analyzed because of the difficulty with the data. The final list includes 55 USGS monitors, 17 STORET monitors (recall that STORET contains data from numerous state and local agencies), and 11 WDNR monitors. Periods of record range from one to five years. TABLE 8 lists those sites contained in the original group of 104 that were not analyzed. The reason or reasons for their rejection are also listed. Appendix B contains the list of all monitors considered for analysis.

Daily rainfall correlations were completed at most of the USGS monitor sites. The prohibitive expense of the National Climatic Center data discouraged the completion of the rainfall correlation at the STORET and WDNR sites.

TABLE 8. ELLIGIBLE SITES NOT ANALYZED AND REASONS

State	Name of site	Data base*	Reason(s) not included
Georgia	Peachtree Cr. near Atlanta	GS	Unable to locate records in archive files
	Ocmulgee R. near Warner-Robins	GS	Unable to locate records in archive files
Illinois	Calumet R. STW	G01	Chicago Sanitation District would not provide data at reasonable cost
	Chicago R. Bridge	G01	Chicago Sanitation District would not provide data at reasonable cost
	Chicago Sanitation & Ship Canal at Lockport	G01	Chicago Sanitation District would not provide data at reasonable cost
Louisiana	Houma Nav. Canal near Dulac	GS	Unable to obtain rain or flow data - marginal site
Massachusetts	Connecticut R. at Agawam	GS	Unable to obtain flow or rainfall for correlation
	Merrimac R. above Concord R. at Lowell	GS	Unable to obtain flow or rainfall for correlation
New Jersey	Passaic R. at Little Falls	GS	Unable to locate records in archive files
Ohio	Cuyahogu R. at Superior St. Bridge	GS	Unable to locate records in archive files
	Ohio R. at West End (Cincinnati)	R02	ORSANCO site - data processing cost too high
	Ohio R. at Andersons Ferry	R02	ORSANCO site - data processing cost too high
Oregon	Willamette R. at Portland	EPA	Data not found in STORET files
	Willamette R. at Oregon City	EPA	Data not found in STORET files
	Willamette R. above Oregon City	EPA	Data not found in STORET files
Pennsylvania	Allegheny R. at Oakmont	R02	ORSANCO site - data processing cost too high
	Beaver R. at Beaver Falls	R02	ORSANCO site - data processing cost too high
	Kiskiminetas R. at Vandergrift	R02	ORSANCO site - data processing cost too high
	Monongahela R. at S. Pittsburgh	R02	ORSANCO site - data processing cost too high
West Virginia	Ohio R. at Huntington	R02	ORSANCO site - data processing cost too high

*GS = U.S. Geological Survey, G01 = Metropolitan Sanitation District of Greater Chicago, R 02 = ORSANCO, and EPA = STORET.

The results of the daily correlation study for all the sites examined are presented in Appendix C. TABLE 9 lists those USGS, STORET, and WDNR monitors that were considered for hourly examination. As mentioned previously, these are sites for which the probability of lower than average dissolved oxygen reached 60 percent on days with higher than average flow or rainfall.

For convenience in identifying the sites with strong correlations, TABLE 9 lists the names with no accompanying data. Listed first in TABLE 9 are those USGS sites that exhibited a strong correlation (60 percent or greater) between higher than average flow and low DO. Listed second are those STORET monitors that exhibited a strong correlation with flow. The WDNR monitors with strong flow correlation are listed next. The final group of stations in TABLE 9 are those USGS sites that exhibited a strong correlation (60 percent or greater) between days with rainfall and periods of lower than average DO.

In TABLE 9 some stations, such as the Mad River at Dayton, exhibited strong correlations between both flow and rainfall and low DO. Such stations appear twice in the listing.

TABLES 10 and 11 provide daily correlation analysis data for the stations listed in TABLE 9. The information in TABLES 10 and 11 is taken from Appendix C. Data are presented only for those years that exhibited a 60 percent probability of low DO at times of higher than average flow (TABLE 10) or days with rainfall (TABLE 11). These data are included here for the convenience of the reader in determining why the sites were chosen for possible hourly analysis. Three types of statistics are included in each table: the probability of a worse-than-average DO deficit, the strength of the deficit, and the average percentage saturation occurring when the DO deficit is worse than average. The three types of statistics answer the following six questions about a given monitor site:

- What is the probability at this station that a worse-than-average (seven-day moving) DO deficit will occur on a wetter-than-average (seven-day moving) day?

- What is the probability at this station that a worse-than-average (seven-day moving) DO deficit will occur on a dryer-than-average (seven-day moving) day?

- If the DO deficit on a particular wetter-than-average day is worse than average, how much worse is it?

TABLE 9. MONITOR SITES EXHIBITING A 60 PERCENT OR GREATER PROBABILITY OF LOW DO DURING HIGH FLOW OR PERIODS OF RAINFALL

Agency	Correlation	Monitor sites
USGS	Flow	North Nashua R. near Lancaster (Leominster), MA.
		Westfield R. at Westfield, MA.
		Wilsons Cr. near Springfield, MO.
		Delaware R. at Trenton, NJ.
		Manasquan R. near Squankum, NJ. (later rejected for lack of urban area)
		Raritan R. near South Bound Brook, NJ.
		Ashtabula R. at Ashtabula, OH.
		Hocking R. below Athens, OH.
		Little Miami R. at Miamiville (Milford), OH.
		Little Miami R. near Spring Valley, OH.
		Mad R. near Dayton, OH.
		Maumee R. at Defiance, OH.
		Portage R. at Woodville, OH.
		Sandusky R. near Upper Sandusky, OH.
		Scioto R. at Chillicothe, OH.
		S. Umpqua R. near Brockway, OR
		Delaware R. at Bristol, PA.
		Delaware R. at Chester, PA.
		Trinity R. below Dallas, TX.
EPA (STORET)	Flow	S. Platte R. at Denver, CO., Burlington Ditch at York St., MDSDD #1
		S. Platte R. at Denver, CO., S. Platte R. at 60th ave., MDSDD #1
WDNR	Flow	Wisconsin R. at Biron, WI.
		Wisconsin R. at Dubay Dam, WI.
		Wisconsin R. at Petenwell, WI.
USGS	Rainfall	Connecticut R. at W. Springfield, MA.
		Westfield R. at Westfield, MA.
		Center Cr. near Carterville, MO.
		James R. near Boaz, MO.
		Wilsons Cr. near Battlefield, MO.
		Wilsons Cr. near Springfield, MO.
		Delaware R. at Trenton, NJ.
		Ashtabula R. at Ashtabula, OH.
		Blanchard R. near Findlay, OH.
		Cuyahoga R. at Independence, OH.
		Cuyahoga R. at Old Portage, OH.
		Grand R. at Painesville, OH.
		Little Miami R. near Spring Valley, OH.
		Mad R. near Dayton, OH.
		Mahoning R. at OH.-PA. State Line, OH.
		Sandusky R. near Upper Sandusky, OH.
		Scioto R. at Chillicothe, OH.
		Lehigh R. at Easton, PA.

TABLE 10. MONITOR SITES WITH 60 PERCENT OR GREATER PROBABILITY OF LOW DO AT TIMES OF HIGH FLOW

Monitor site by state and agency*	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO (USGS)							
Ashtabula R. at Ashtabula	75	.63	.49	1.23	1.21	.64	.72
Hocking R. below Athens	76	.67	.45	1.44	1.40	.84	.86
Little Miami R. at Miamiville (Milford)	73	.66	.40	1.61	2.01	.83	.85
	74	.67	.37	1.56	1.42	.84	.86
Little Miami R. near Spring Valley	74	.65	.43	1.33	1.18	.73	.74
	75	.67	.45	1.18	1.14	.72	.76
Mad R. near Dayton	72	.63	.47	1.25	1.13	.71	.71
Maumee R. at Defiance	73	.66	.41	1.37	1.29	.72	.67
	75	.60	.38	7.64	1.77	.77	.76
Portage R. at Woodville	73	.60	.44	1.43	1.75	.56	.62
	75	.68	.40	1.76	1.72	.77	.83
Sandusky R. near Upper Sandusky	73	.60	.46	1.58	1.86	.83	.76
	76	.64	.46	1.34	1.27	.71	.74
Scioto R. at Chillicothe	72	.64	.48	1.21	1.15	.41	.51
MASSACHUSETTS (USGS)							
North Nashau R. near Lancaster (Leominster)	70	.63	.50	1.17	1.17	.53	.62
Westfield R. at Westfield	75	.62	.48	1.69	2.65	.78	.88

*Stations are grouped by state, states are in alphabetical order, stations are alphabetized within groups.

(continued)

TABLE 10 (continued).

Monitor site by state and agency	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
MISSOURI (USGS)							
Wilsons Cr. near Springfield	73	.70	.42	1.27	1.20	.60	.64
	75	.81	.39	1.27	1.16	.56	.69
	76	.77	.44	1.28	1.14	.58	.65
NEW JERSEY (USGS)							
Delaware R. at Trenton	73	.64	.45	1.83	6.66	.85	.93
	75	.61	.40	2.79	3.73	.91	.96
Manasquan R. at Squankum (This station later abandoned for lack of urban area; it is near a swamp.)	71	.61	.58	1.12	1.13	.51	.55
	72	.66	.52	1.22	1.11	.50	.56
Raritan R. near South Bound Brook (below Callo Dam at Boundbrook)	75	.60	.37	1.60	1.65	.71	.80
OREGON (USGS)							
Umpqua R. near Brockway	76	.63	.55	3.82	2.30	.82	.83
PENNSYLVANIA (USGS)							
Delaware R. at Bristol	75	.71	.43	1.33	1.24	.84	.84
Delaware R. at Chester	73	.67	.65	1.13	1.61	.36	.42
TEXAS (USGS)							
Trinity R. below Dallas	77	.60	.52	1.13	1.14	.28	.26

(continued)

TABLE 10 (continued).

Monitor site by state and agency	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
COLORADO (EPA)							
S. Platte R. at Denver, Burl. Ditch at York St. MDSDD #1	71	.60	.44	1.35	1.30	.72	.72
S. Platte at Denver, S. Platte at #60 Ave, MDSDD #1	76	.66	.44	1.21	1.28	.61	.70
WISCONSIN (WDNR)							
Wisconsin R. at Biron	74	.64	.46	1.48	1.13	.60	.62
Wisconsin R. at Dubay	74	.60	.52	1.08	1.11	.36	.44
Dam	76	.64	.50	1.08	1.13	.36	.44
Wisconsin R. at Petenwell	73	.60	.40	1.20	1.16	.56	.62

TABLE 11. USGS MONITOR SITES WITH 60 PERCENT OR GREATER PROBABILITY OF LOW DO ON DAYS WITH RAINFALL

Monitor site *	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
MASSACHUSETTS							
Connecticut R. at W.	73	.60	.52	1.67	2.98	.80	.76
Springfield	74	.66	.47	1.32	1.21	.78	.81
(Thompsonville)	75	.63	.47	1.26	1.23	.81	.83
Westfield R. at Westfield	75	.63	.45	2.13	2.46	.81	.87
MISSOURI							
Center Cr. near Carterville	74	.64	.49	1.14	1.10	.59	.62
	75	.65	.50	1.14	1.15	.54	.54
James R. near Boaz	73	.64	.47	1.14	1.12	.57	.58
	74	.64	.54	1.13	1.13	.49	.48
	75	.65	.53	1.14	1.09	.44	.45
	76	.63	.52	1.11	1.11	.30	.28
Wilsons Cr. near	74	.63	.56	1.08	1.10	.09	.10
Battlefield	75	.62	.53	1.12	1.08	.14	.14
	76	.63	.52	1.06	1.05	.03	.04
Wilsons Cr. near	75	.67	.38	1.26	1.15	.61	.68
Springfield	76	.77	.43	1.24	1.16	.61	.64
NEW JERSEY							
Delaware R. at Trenton	72	.62	.46	1.79	5.35	.86	.87
OHIO							
Ashtabula R. at Ashtabula	75	.63	.45	1.24	1.18	.70	.68
	76	.67	.42	1.22	1.24	.69	.68

*Stations are grouped by state, states are in alphabetical order, stations are alphabetized within groups.

(continued)

TABLE 11 (continued).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO (continued)							
Blanchard R. near Findlay	73	.65	.48	1.29	1.20	.65	.58
	75	.62	.44	1.17	1.16	.50	.55
	76	.64	.49	1.22	1.19	.57	.59
Cuyahoga R. at Independence	73	.60	.41	1.25	1.22	.72	.70
Cuyahoga R. at Old Portage	76	.66	.44	1.27	1.19	.67	.75
Grand R. near Painesville	75	.60	.59	1.19	1.16	.72	.66
Little Miami R. near Spring Valley	74	.60	.43	1.27	1.21	.73	.74
	75	.61	.43	1.17	1.14	.74	.75
Mad R. near Dayton	72	.66	.43	1.20	1.14	.72	.70
	73	.64	.34	1.26	1.14	.78	.78
	74	.60	.45	1.17	1.13	.73	.72
	75	.63	.41	1.20	1.20	.74	.75
	76	.65	.45	1.21	1.15	.68	.70
Mahoning R. at OH.-PA. State Line below Lowellville	76	.60	.44	1.18	1.14	.54	.52
Sandusky R. near Upper Sandusky	74	.62	.45	1.77	–	.71	.70
	75	.62	.41	1.38	2.62	.70	.74
	76	.69	.42	1.40	1.21	.71	.75
Scioto R. at Chillicothe	76	.60	.39	2.15	1.31	.54	.58

(continued)

TABLE 11 (continued).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
PENNSYLVANIA							
Lehigh R. at Easton	72	.67	.51	1.35	1.56	.77	.76
(Glendon)	73	.62	.45	1.50	1.60	.83	.82

- If the DO deficit on a particular dryer-than-average day is worse than average, how much worse is it?

- On wetter-than-average days when the DO deficit is worse than average, what percentage of saturation is present?

- On dryer-than-average days when the DO deficit is worse than average, what percentage of saturation is present?

The first and third questions were of primary concern to this study. If the answer to the first was "yes" and the answer to the third was "less than 75 percent saturation," then the site in question was felt to be worth closer examination.

The results of the analysis to examine the DO deficit levels for days on which the flow equaled various percentages of the mean annual value are not presented here. In general, they were used to augment or confirm judgments made from information in Appendix C.

The following section describes the more-detailed analyses that were performed at the sites that exhibited strong correlations. The detailed analysis was designed to determine which of the sites with strong correlations also had water quality standard violations.

SECTION 7

DETAILED SITE ANALYSIS

GENERAL CONSIDERATIONS

Water quality monitor sites where correlations existed between rainfall and/or flow and low DO were identified in Section 6. The daily data used to identify these sites did not allow a determination of specific water quality standard violations. Hourly data analysis was required at sites that showed strong deficits (DO levels less than 75 percent saturation). For these reasons and because of other contract requirements, it was necessary to examine those sites with correlations in greater detail.

The contract requirement that required the most additional information was the Streeter-Phelps analysis. This is a procedure used to calculate the location of the maximum DO deficit downstream of point or distributed sources of oxygen-demanding material. The purposes of such analysis were to determine if a given water quality monitor was in a position to sense the maximum deficit from urban runoff and if observed deficits appeared reasonable based on the best estimates of input loads. Urban population, drainage area, streamflow, temperature, BOD loads, and other data were required.

In addition to selecting sites for hourly and Streeter-Phelps analysis, it was desired to form some opinion on why a correlation might exist between flow/rainfall and low DO at a given site. Information was needed on travel time from the urban area to the monitor, distance from the rain gage to the urban area, and other factors that might influence the DO that a monitor "sees."

The overall process of the detailed site analysis studies will now be described. Specific aspects of the analysis, such as Streeter-Phelps, will be singled out and discussed in detail. These detailed discussions occupy the remainder of the section.

The first step in the detailed site analysis was the gathering of available maps. The monitor and flow gage and the weather station, if any, were then located precisely. An information sheet that summarized what could be learned from USGS records, the map, or other sources was next filled out. Information sheet data were used to select sites with the simplest hydraulic conditions for analysis by the Streeter-Phelps technique. Finally, the plots of daily average flow, DO, and rainfall values were examined and periods for hourly analysis were selected. From 10 to 30 days or more of hourly data were examined at each site where the hourly data could be obtained. The total of all this information was then studied carefully to see what could be concluded. The results form the substance of Section 8, which follows.

GENERALIZED INFORMATION ANALYSIS

The gathering of information at each site was systematized by developing a standard form. The two-page form, filled out for the Scioto River at Chillicothe, Ohio, monitor is illustrated in Exhibits 2 and 3.

It was originally intended that completed forms for each of the sites in TABLES 9, 10, and 11 would be included as an appendix to this report. However, experience indicated that much of the information was unavailable. For this reason, each site will be discussed individually in the appendix and as much general information as possible tabulated there.

In order to keep the main body of the text to a reasonable size, the remainder of the discussion on the completion and use of the site analysis forms will be structured around the Scioto River at Chillicothe. This will serve as an example of the method used. The reader is referred to Appendix D, where the remaining sites, as well as the Scioto, are presented.

The first step in filling out the analysis forms was usually to assemble USGS 7.5-minute topographic sheets to form a complete picture of the particular urban area in question. These ranged in size from a single sheet to as many as nine sheets for the Philadelphia-Trenton area. Next, the water quality monitor, the stream gage, and the precipitation station were located. This was done by plotting the reported latitude and longitude of the facilities. This had been done in the early phases of the study to select monitors for inclusion in the daily analysis. Many of the maps used, however, were in the USGS library. More maps were purchased and brought to Sutron for the detailed analysis work.

The assembled maps were large and cumbersome. Therefore, a sketch of relevant features was transferred to the site form. This aided in remembering each one later. Any outstanding features such as industry or sewage treatment plants were noted. Other information gathered from the maps included the urban drainage area, stream width, the distance from monitor to stream gage, and distances from the monitor to sewage outfalls. The

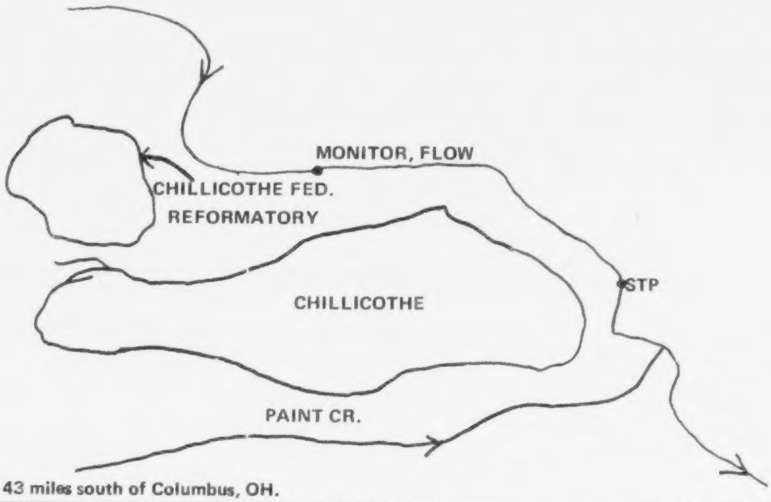
Exhibit 2. Site analysis form — Streeter-Phelps.

MONITOR NAME: Scioto R. at Chillicothe, OH. AGENCY: USGS

MONITOR LOCATION: Lat.: 39 20 29 Long.: 825816 AGENCY ID NO.: 03 231 500

SKETCH OF SITE:

POP. OF COLUMBUS
566,600 [1,069,400]



PHYSICAL DESCRIPTION: 43 miles south of Columbus, OH.

OUTSTANDING FEATURES: Sewage disposal downstream of monitor, no obvious problems

STREAM GAGE NAME: Scioto R. at Chillicothe, OH. AGENCY: USGS

STREAM GAGE LOCATION: Lat.: 392029 Long.: 825816 AGENCY ID NO.: 03231500

PRECIPITATION GAGE NAME: Chillicothe - Mound City NWS ID NO.: 1528

DISTANCE – MONITOR TO STREAM GAGE: 0 DISTANCE – RAIN GAGE TO MONITOR: ~2 mi

QUALITY OF RECORDS: Looks good most of the time

DESCRIPTION OF STREAM:

APROX. WIDTH: 250 ft AVG. DISCHG.: ~3400 cfs RANGE OF DISCHG.: 500-50,000 cfs

APROX. DEPTH AT AVG. Q.: APROX. MEAN VEL. AT AVG. Q.:

OTHER INFORMATION:

Exhibit 3. Site analysis form.

MONITOR NAME: Scioto R. at Chillicothe, OH.

TOTAL DRAINAGE AREA AT MONITOR: 3850 TOTAL URBAN DRAINAGE: 3-4 mi^2

% URBAN CONTRIBUTING AT MONITOR: 50% % CONT. URB./TOTAL: <1%

APROX. POPULATION OF URBAN AREA:

RESULTS OF CORRELATION ANALYSIS:

DAILY FLOW – COMMENT ON PROBABILITY OF OCCURRENCE: .64 - 1972

COMMENT ON STRENGTH OF SAG: 1.21 wet, 1.15 dry - 1972 / .41% wet, .51 dry - 1972

DAILY RAIN – COMMENT ON PROBABILITY OF OCCURRENCE: .6 - 1976

COMMENT ON STRENGTH OF SAG: 2.15 wet, 1.31 dry - 1976 / 54% wet, 58% dry - 1976

STREETER-PHELPS ANALYSIS PARAMETERS

STREAM Q, cfs: WASTE DISCHG., cfs: STM. VEL., ft/sec.:

DEPTH, ft.: INITIAL DEFICIT, mg/l:

DEFICIT INFLOW, no./day: BOD INFLOW, no./day:

DIST. BOD SOURCE, mg/l/day: UPSTRM. BOD IN RIVER, mg/l:

DIST. BENTHAL DMND., g/m^2/day: REAERATION COEF., Ka, l/day:

BOD DECOY COEF., Kr, l/day: DEOXYGENATION COEF., Kd, l/day:

STREETER-PHELPS RESULTS

COMMENT ON MONITOR LOCATION:

COMMENT ON STREAM MILES AFFECTED:

CONFIDENCE IN RESULTS:

ANALYSIS OF PROBLEM AT THIS SITE:

Chillicothe is 44 mi downstream of Columbus. This could be near the Columbus sag point - bad water quality probably originates at Columbus.

urban area was estimated as accurately as possible from the rose-tinted areas on the maps. Distances were measured by map scale and dividers.

After tabulating the physical features of the site, the stream flow was examined. The flow and DO records were gathered and the range of values entered. The plots of DO and discharge were examined to determine the percentage of missing records. This examination was combined with the quality estimates in the agency reports to rate the record. Records were "excellent" if only one or two weeks a year were missing. A "good" rating went to stations with one or two months missing. A "poor" rating went to all others.

While examining the flow records, typical July-August low flow values were selected. These were for later use in the Streeter-Phelps analysis (if performed). If rating curves were available, they were used to determine the depth and velocity, which were also required for Streeter-Phelps.

The results of the daily correlation analysis were entered on the form in a summarized fashion. This was done to give at a glance the magnitude of the "problem" at each site. This was omitted in cases where there was too much information to fit. A note was entered referring to a separate summary table.

The population figures were obtained from a World Almanac from the 1970 census. No attempt was made to account for growth increases. The maps were often more out of date than the census. For consistancy, no adjustments were made to "urban" areas either.

The Streeter-Phelps portion of the site forms was completed only if the analysis was actually performed. Development of complex water quality models was not within the Scope of Work. For this reason, sites with fairly simple hydraulic conditions were selected for analysis. Meaningful analysis using the Streeter-Phelps method required streams with few tributaries and not too many waste sources. Five sites were required by the contract. Thirteen were done because the writers felt that it contributed a worthwhile insight into the location of monitors. The actual Streeter-Phelps procedure is complex enough to warrant separate discussions. It is the subject of the following section.

Streeter-Phelps Analysis

The bulk of the "Streeter-Phelps" theory used in this study was derived from Thomann's (2) excellent book on water quality management. Virtually, all of Section 5 of the book is directed toward one-dimensional modeling of stream quality. Streeter-Phelps is a subset of the methods covered.

The term "Streeter-Phelps" is somewhat misleading. The original work of Streeter and Phelps in 1925 was directed specifically at determining the DO deficit versus distance caused by a point source of carbonaceous BOD (CBOD), L_o, and some initial DO deficit, D_o. In the intervening years, other researchers have added additional capabilities to the original model. These include nitrogenous BOD (NBOD), photosynthesis, respiration, benthal oxygen demand, and distributed sources of CBOD and NBOD.

The "Streeter-Phelps" equations used in this study were selected primarily on the basis of data available to set the various parameters. In all cases, the data were very limited. It was necessary to work from good estimates of the urban area, the population, and the data obtained for the study, that is, flow, temperature and DO levels. No CBOD, NBOD, photosynthesis, respiration, or rate constant information was available. In the absence of these key numbers, it was decided to be consistent with the technique, even though accuracy was out of the question.

The equation chosen for use is as follows:

$$
\begin{aligned}
D = {} & \Bigl[\Bigl(W_d/Q\Bigr) + D_o\Bigr] \exp \Bigl[-K_a(X/V)\Bigr] \\
& + \Bigl(K_a/\Bigl(K_d - K_r\Bigr) \Bigl\{\exp \Bigl[-K_r(X/V)\Bigr] - \exp \Bigl[-K_a(X/V)\Bigr]\Bigr\}\Bigr) L_o \\
& + \Bigl(K_d/\Bigl(K_a - K_r\Bigr) \Bigl\{1 - \exp \Bigl[-K_a(X/V)\Bigr]\Bigr\}\Bigr) L_{rel} \\
& + \Bigl(K_d/\Bigl(K_a - K_r\Bigr) \Bigl\{\exp \Bigl[-K_r(X/V)\Bigr] - \exp \Bigl[-K_a(X/V)\Bigr]\Bigr\}\Bigr) L_{rd} \\
& + \Bigl\{1 - \exp \Bigl[-K_a(X/V)\Bigr]\Bigr\} \Bigl(S_b/K_a\Bigr) ,
\end{aligned}
$$

where D = DO deficit (milligrams per liter),

W_d/Q = weight of initial DO deficit divided by river discharge (W_d is expressed in pounds, Q in cubic feet per second, and the quotient converted to milligrams per liter),

exp = exponential function,

K_a = reaeration rate constant (days $^{-1}$),

X = distance from initial source (miles),

V = mean stream velocity (miles per day),

K_d = CBOD oxidation rate coefficient (days $^{-1}$),

K_r = CBOD settling plus oxidation rate coefficient (days $^{-1}$),

L_o = initial point source CBOD (milligrams per liter),

L_{rd} = distributed CBOD source (milligrams per liter per day), and

S_b = oxygen uptake of benthic deposits (milligrams per liter per day).

The initial value of CBOD, L_o, is found by a mass balance at X = 0 as

$$L_o = (W + L_u Q)/Q + Q_w$$

where W = weight of CBOD input (pounds),
L_u = upstream CBOD (pounds), and
Q_w = waste discharge rate (cubic ft per sec).

The quotient is converted to milligrams per liter.

Benthal demand, S_b, is normally reported as grams oxygen per meter squared per day. It is converted to milligrams per liter per day by dividing by the hydraulic radius of the channel.

Photosynthesis/respiration effects were not considered. Likewise NBOD, both point source and distributed, were not considered.

Before discussing the means used to evaluate the many coefficients and parameters in the equations, it is worth discussing the method in general. There are a number of reasons to be skeptical of the outcome from the start. First, the equation is one-dimensional in nature. All waste sources and other parameter values are assumed to be uniformly distributed across the length and breadth of the stream. Experience has shown this to be a fairly reasonable assumption for the case in which lateral mixing is rapid or in which waste sources are deliberately introduced through diffusers placed across the channel. Second, the equations were designed for steady state conditions. That is, the waste discharges, the stream flow, and all the rate controls are time invariant. Assuming such condition to exist under the influence of storm runoff is highly suspect. Discharge increases of factors of ten are common in small streams under summer storm runoff conditions. Peak flows seldom last an entire day. Often storm hydrographs last less than one day. Finally, as mentioned earlier, virtually no data are available on the various rate constants. Empirical formulas are available, but seldom specific measurements.

The writers would have preferred to see the "Streeter-Phelps" analysis replaced with a coupled unsteady-flow/water-quality model. This would have been much more realistic and is still strongly recommended. However, this would require a concentrated data collection effort at one site. Recommendations on suitable places will be made later.

Since application of the Streeter-Phelps methodology was a requirement in the Scope of Work, every effort was made to implement it in a consistent and reasonable way. Although it was not within the Scope of Work to develop water quality models, the first step was to develop a flexible Streeter-Phelps solution algorithm. Direct solution of the equation confined the answer to a single point source of CBOD as well as single identifiable point sources. In order to handle these situations, a model was developed capable of superimposing solutions at various distances. A starting position, X=0, was specified for each point source desired, and the program kept track of each and added them all together to form an overall DO deficit profile for the reach in question. Take for example a situation in which three sewage treatment plants are present in a city seven miles long and a reach length of 70 miles was desired. The procedure is as follows: First, assign X = 0 to the upstream edge of the city and solve the equation for a distributed demand over the seven miles of city. Store this result. Next, solve the equation for a point source of CBOD at the location of the first treatment plant. Add this to the first solution with the origin offset appropriately to reflect the plant location. Finally, do the same for the other two plants.

In practice, the scheme was implemented on a large desktop calculator with a plotter. The "Streeter-Phelps" equation was solved at one-quarter-mile intervals for whatever total reach length was specified. A large one-dimensional matrix saved the solutions and accumulated them for plotting. The calculator handled all the offset calculations automatically. Examples of the results will be shown after discussing parameter estimation.

The following is a list of the parameters that had to be estimated for the Streeter-Phelps technique:

- Flow parameters: stream distance
  discharge
  depth
  flow velocity
- Rate constants: K_a, K_r, K_d
- Demand and loading constants: D_o, L_o, Q_w, L_{rd}, S_b, W.

As mentioned previously, the hope for accuracy of the technique was not great. Consistency was sought, however, so that relative results could be compared. Thus, each site considered for "Streeter-Phelps" analysis was treated in exactly the same way.

The flow parameters were the easiest to estimate. Even here, however, detail was lacking. Stream distances were measured by picking a starting point for X = 0. This was usually the upstream edge of the urban area as indicated by the rose-colored area on the 7.5-minute quad sheets. In some instances, it was taken as the outfall of the farthest upstream treatment plant. Stationing in miles was then established by using dividers set at one-quarter-mile spacing proceeding down the channel centerline.

When very large distances (10 miles or more) were involved, atlases or 1:25,000 scale maps were used. In the absence of suitable maps, channel length was estimated using a standard geomorphology formula (Leopold et al. (9)). This states that channel length, L, is proportional to drainage area to the 1.4 power. The USGS publishes drainage areas at all gages and the distance between each could be found as

$$\Delta L = A_{d_1}^{1.4} - A_{d_2}^{1.4} \quad .$$

Values obtained by this method were always checked for reasonableness by measuring the straight-line distance and assuring that ΔL was neither shorter nor greater than a factor of five longer.

The magnitude of discharge to use was an important consideration. The final decision was to use two separate values for each site. First, a typical July-August low flow was picked by eye from a year when a correlation existed between discharge or rainfall and low DO. This was done by looking at the plots of mean daily discharge and selecting the low point. Next, a typical July-August storm flow was selected. This was also chosen of the mean daily value plots.

The reasoning behind using two flows was based on the Streeter-Phelps limitation of steady flow. It seemed unwarranted to merely change the loading into the low flow conditions to simulate storm events when it was known that storm flows were often 10 times or more greater than low flow. By using realistic low flow loadings in a low flow and realistic storm loadings in a storm flow, it was hoped that reasonable results would be obtained.

After selecting the two discharges, it was necessary to estimate the depth and flow velocity. Readers familiar with river mechanics can appreciate the difficulty of assigning a single depth and velocity to reaches as long as 60 miles. As stated earlier, the objective was not to reinvent the water quality model, so reach-by-reach depths were not entered. If a rating curve was available, the depth and area were taken from that. If no rating curve was available, the widely used Manning's equation for discharge,

$$Q = (1.486/n)\ AR^{2/3}S_o^{\ 1/2} \ ,$$

was used to estimate depth. Here, n = channel roughness parameter, taken to be 0.035 (typical of many open channels); A = cross-sectional area, in square feet; R = hydraulic radius (approximately equal to depth for wide channels); and S_o = the energy slope (bed slope for steady flow in a uniform rectangular channel). By assuming a rectangular channel, R = depth, and taking S_o = bed slope,

$$Q = (1.486/n)\ WY(Y^{2/3})S_b^{1/2}$$

$$= (1.486/n)\ WY^{5/3}S_b^{1/2}\ .$$

By estimating the width, W, and the slope, S_b, from maps, the depth was easily computed. Once the depth was known, the velocity was also easily computed.

The rate coefficients were all computed from standard formulas or typical values reported in the literature. The reaeration rate coefficient, K_a, was extensively studied by Rathbun and Bennett of the USGS (10). They recommend the formula

$$K_a = 2.59\ (V^{0.674}/Y^{1.865}),$$

where Y is mean stream depth. This was based on a very large data base in a variety of rivers collected by many other researchers.

The CBOD oxidation and settling rate constants, K_r and K_d, are normally determined in the laboratory from stream samples. In the absence of such samples, rate constants typical of streams in urban areas were used. Thomann (2) gives a table of values of typical rate constant, K_r (values at 20°C):

$K_r = 1.0 \rightarrow 3.0$ in shallow streams, high oxidation, rapid settling

$= 0.6 \rightarrow 0.8$ some settling

$= 0.1 \rightarrow 0.6$ "normal"

$K_d \approx 0.5\ K_r$ "normal."

For this study, both K_d and K_r were considered to be 0.3. This was approximately the middle of the "normal" range. Rate constants were adjusted for temperature by the formula:

$$K(T) = K\ (20^{\circ}C)\ (1.024^{(T-20)}).$$

It was particularly difficult to make good estimates of the CBOD loads and the upstream DO levels. Again, the goal was one of consistency rather than accuracy. The first loading considered was usually the initial point source of CBOD. Two calculations were performed. The first was for "normal" sewage flow. The second was for "storm" flow. If more than one treatment plant was involved, more calculations were made and the multiple solution capability used.

The "normal" sewage flow was readily computed from the population of the urban area. The population figures were obtained from a World Almanac, if possible. If not possible, a population density of 7000 per square mile was assumed. This figure was obtained by averaging 25 cities ranging in population from 50,000 to 5,000,000. Raw-sewage flow is characteristically taken to be 125 gallons per capita per day. This gave Q_W. The raw weight per day, W, of the CBOD load was computed by multiplying the population by 0.5 pounds per capita per day (typical according to Thomann (2)). This was multiplied by 0.15 to give an estimate of the treated load (i.e., we assumed 85 percent treatment efficiency). The "Streeter-Phelps" calculator program used the information to compute L_o.

The "storm" loadings were a somewhat more difficult matter. Two steps were necessary. First, an assumption was required regarding the quantity of rainfall and the percentage of runoff. Second, the CBOD load associated with this runoff was required.

Thomann (2) again provided an answer. A study of combined sewer overflows in North Philadelphia, Pennsylvania, produced a graph of CBOD load in pounds per day per acre versus storm duration in hours at various intensities. Arbitrarily a rainfall rate of 0.15 inch per hour and a storm duration of 10 hours was selected. This gave 1.5 inches total rainfall, which seemed somewhat reasonable. The graph indicated a 10 pounds per acre per day load for these conditions. Twenty percent of the water that fell was assumed to run off. This again was based on the Philadelphia study as reported by Thomann. The procedure then was: (a) multiply the urban area by 10 pounds per acre per day to get W, (b) multiply the urban area by 1.5 inches and convert to cubic feet, (c) divide the cubic feet by 10 hours and convert to cubic feet per second, (d) multiply cubic feet per second by the 20 percent runoff factor to get Q_W. If the urban area had a single treatment plant, this "storm" load was entered as a point source there. If more than one plant was present, the load was entered at the midpoint of the urban area. Typical "storm" loadings computed by this method roughly equaled the estimated raw sewage yield. This seemed reasonable as the Durham, North Carolina, studies (1,3) and a study of San Francisco CSO's indicate that such discharges are roughly equal to raw sewage in quality.

Three parameters remain. These are D_o, L_{rd}, and S_b. The value of D_o, the initial deficit, was assumed to be zero. That is, the stream was assumed saturated at $X = 0$. This was done simply for lack of a way to make an intelligent guess. Similarly, the distributed CBOD source was set to zero. The solution was extremely sensitive to this value and again no good way was available to estimate it. The distributed benthal demand. S_b, was taken as 1.5 grams per meter squared per day. According to Thomann, this is typical of aged municipal sewage. The S_b term was needed only when a concentration of industry or treatment plants were present.

TABLE 12 identifies the 13 sites where the Streeter-Phelps analysis was applied. As mentioned previously, these are sites on rivers with few tributaries and fairly well-defined waste loads. These were felt to be sites where analysis would be most meaningful. The results for the Scioto River at Chillicothe, Ohio, are illustrated in Figure 4. Figure 4 is fairly typical of all the Streeter-Phelps analysis results. Plotted on the graph are DO deficit versus distance below Columbus, Ohio. Columbus is the only significant urban area upstream of Chillicothe. Two DO deficit curves are illustrated. The lower curve represents the theoretical DO deficit for August low-flow conditions. The upper curve represents the theoretical deficit for an August storm flow with urban runoff contributing oxygen-demanding material at Columbus. The location of the Chillicothe monitors is shown at 80 miles downstream of Columbus. The DO sag point, or maximum deficit would theoretically occur 26 miles below Columbus. The monitor is, thus, poorly located. Water quality violations could occur near the sag point and not be observed at Chillicothe. The analysis indicates that a deficit of slightly over 4 mg/l could be observed at Chillicothe during storm flow conditions at Columbus. A deficit of 7 mg/l could theoretically be observed at the sag point. Also illustrated in the figure are the saturation DO levels for 20°C and 27°C. The

TABLE 12. STREETER-PHELPS ANALYSIS SITES

No.	Monitor name
1	Lehigh R. at Easton, PA.
2	Scioto R. at Chillicothe, OH.
3	Sandusky R. near Upper Sandusky, OH.
4	Portage R. at Railroad Bridge at Woodville, OH.
5	Maumee R. at Defiance, OH.
6	Mahoning R. at OH.-PA. State Line below Lowellville, OH.
7	Mad R. near Dayton, OH.
8	Hocking R. below Athens, OH.
9	Cuyahoga R. at Old Portage, OH.
10	Cuyahoga R. at Independence, OH.
11	Blanchard R. near Findlay, OH.
12	Raritan R. near South Bound Brook, NJ.
13	Connecticut R. at West Springfield, MA.

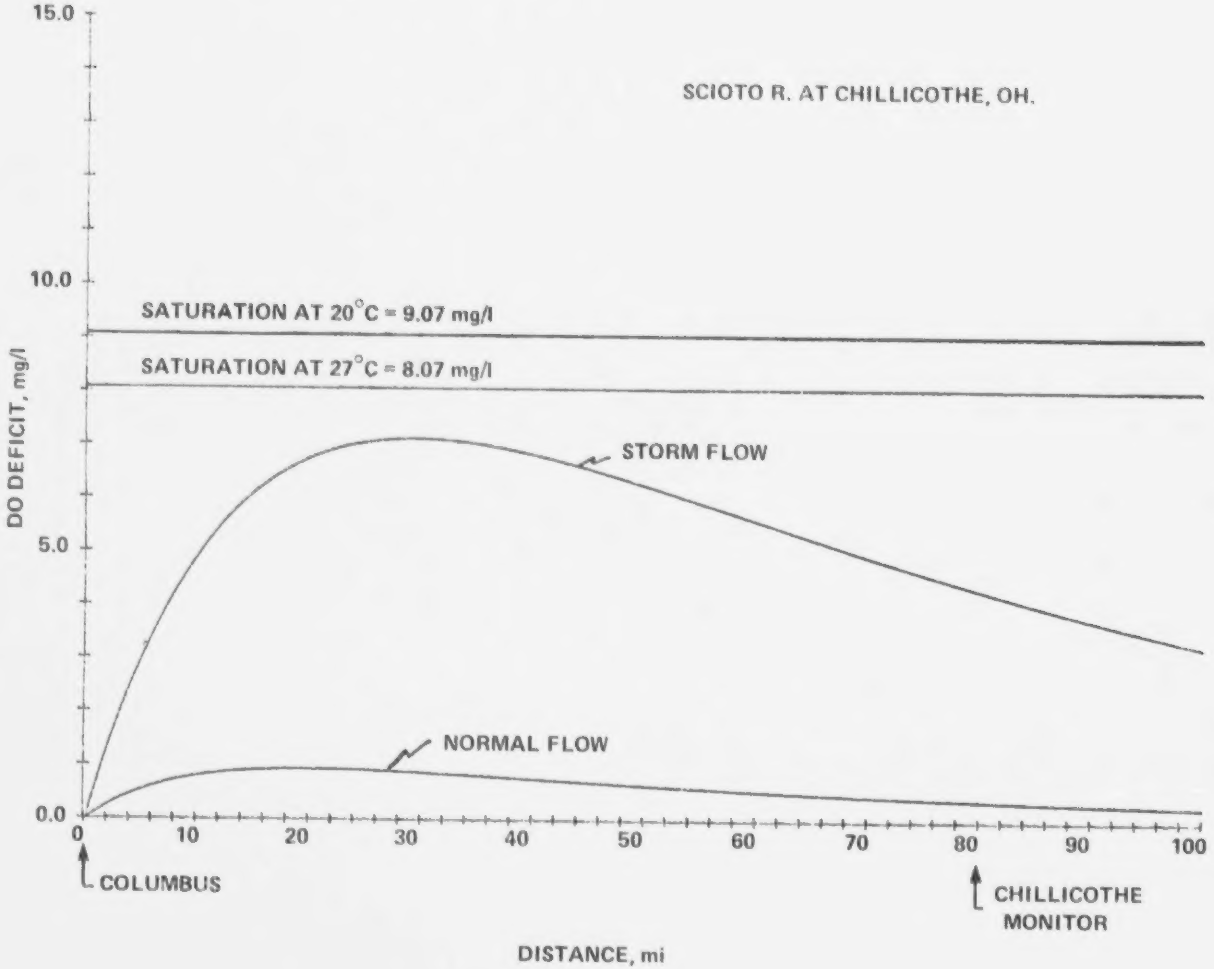


Figure 4. Streeter-Phelps analysis results for Scioto River at Chillicothe, OH.

difference between these lines and the deficit curves is the absolute DO level. In the worst case (27°C), absolute DO levels at Chillicothe could theoretically fall below 4.0 mg/l (8.07 - 4.1) under storm conditions. At the sag point, DO levels of 1.0 mg/l (8.07 - 7.0) could theoretically be observed. These observations are typical of the information available from the Streeter-Phelps analysis. Discussion of the Streeter-Phelps analysis for all 13 sites is included in Appendix D. Reference will be made to the results in Section 8.

Hourly Data Analysis

The last and most important of the detailed site analysis techniques was the hourly data analysis. This was ultimately completed at 22 of the 30 USGS sites that indicated a strong correlation between flow and/or rainfall and periods of low DO. These sites are listed in TABLE 13. No decision process was involved in reducing the number of sites for hourly analysis from 30 to 22. Those sites that are included had hourly data available. The eight missing sites did not.

TABLE 13. SITES AT WHICH HOURLY DATA WERE PROCESSED

No.	Monitor name
1	Connecticut R. at West Springfield, MA.
2	North Nashua R. near Lancaster, MA.
3	Wilsons Cr. near Springfield, MO.
4	Ashtabula R. at Astabula, OH.
5	Blanchard R. near Findlay, OH.
6	Cuyahoga R. at Independence, OH.
7	Cuyahoga R. at Old Portage, OH.
8	Grand R. at Painesville, OH.
9	Hocking R. below Athens, OH.
10	Little Miami R. at Miamiville, OH.
11	Little Miami R. near Spring Valley, OH.
12	Mad R. near Dayton, OH.
13	Portage R. at Railroad Bridge at Woodville, OH.
14	Sandusky R. near Upper Sandusky, OH.
15	Scioto R. at Chillicothe, OH.
16	South Umpqua R. near Roseburg, OR.
17	Delaware R. at Bristol, PA.
18	Delaware R. at Chester, PA.
19	Lehigh R. at Easton, PA.
20	Schuylkill R. at Philadelphia, PA.
21	Trinity R. below Dallas, TX.
22	Trinity R. near Rosser, TX.

Looking at every piece of hourly data available was out of the question. Five years of hourly data for flow, DO, and temperature plus the computation of an hourly DO deficit would be 5.25 million numbers. This would not be infeasible if the numbers were available in digital form. Unfortunately, they are not. All hourly data had to be transcribed by hand from computer listings provided by USGS. Further discussion of this follows later.

Instead of examining all available hourly data for each site, a "windowing" technique was used with daily data. For a given station the plots of mean daily discharge, DO and DO deficit were located for years with a 60 percent or greater probability of a low DO event coinciding with a flow or rainfall event. These were searched to find typical periods ("windows") when such events occurred. Hourly data were then processed for these periods and plotted.

Advantages of USGS Data--

Some explanation of why only USGS sites were used in the hourly analysis and how hourly data are obtained is in order. Several federal and state agencies gather and file hourly data. Most notable of these are USGS, ORSANCO, EPA (through the STORET system), the Metropolitan Sanitation District of Greater Chicago, and WDNR.

Recall from earlier discussions that ORSANCO stores hourly values at some 20 places along and tributary to the Ohio River. There are two major drawbacks to its data. First, no flow data are collected. The COE collects those. Second, the data are given to outside users in a very awkward format for a project such as this. Each file on an ORSANCO digital tape contains data from all the stations reporting on a given hour. Thus, it is necessary to execute 8760 tape reads to recover a single year of data at one station. The computational expense is prohibitive. (This is not an indictment of the method used but simply a warning to other potential users.)

EPA's STORET data base contains several types of data mixed together. There is a good deal of usable daily average data, as mentioned in the section on site screening. The writers were unable to locate hourly data in significant amounts at any sites of interest. The Chattahoochee River near Atlanta, Georgia, monitor is typical. Well over five years of daily data were included in the STORET records. Scattered through this were random days when one or two diurnal oxygen cycles had been sampled on an hourly basis. There were not enough data to contribute to this study.

The Metropolitan Sanitation District of Greater Chicago keeps track of hourly data on a number of sites. However, it is not sufficiently staffed to copy these data onto a digital tape for outside users. It will, however, allow access to its data for hands-on copying of numbers. This represents a sizable manpower cost for useful amounts of data.

The WDNR stores both hourly and daily data on 14 stream sites. It was highly cooperative at providing a tape of the daily average values. No attempt was made to obtain the hourly data because only three of the 11 showed any degree of correlation between rainfall/flow and low DO. Neither of the correlations was exceptionally strong. There is no reason to believe that hourly data could not be readily obtained from WDNR.

Hourly Rainfall Data--

For reasons of economy the hourly rainfall data for the detailed analysis was obtained from a National Climatic Center publication called "Local Climatologic Data." This is a monthly publication that summarizes various data at primary weather stations throughout the country. Each state contains three to five such stations. Each monthly summary contains the hourly rainfall. These data were obtained free from NOAA at no charge. The cost of obtaining hourly data on one year from the National Climatic Center in Asheville, North Carolina, on digital tape is $50.

The rainfall data were entered by hand into files on digital magnetic-tape cartridges. The program for creating the files and plotting the data will be discussed in the next section on USGS hourly data.

Obtaining and Processing USGS Data--

Most USGS data are recorded at monitor or stream gage sites on digital punched tape. In rare instances, the stream gages still record stage on strip chart recorders. The digital tape punches used by USGS are capable of punching at intervals from five minutes to one hour. The tapes are collected once a month or more. The monitors are serviced and brought to working order if necessary when the tapes are changed. Any clock descrepancies or monitor malfunctions are noted on the tape.

The next step in recovering data from the digital punched paper tape is to copy it to magnetic tape. This is done by reading the paper tape via phone connection to the USGS central computer system in Reston, Virginia. There, the digital magnetic tape is created. Some state offices have facilities for making their own magnetic tapes.

The next step in the data recovery process is to examine and edit the numbers on the magnetic tape. It is at this stage that hourly data become available. Standard processor programs are run to produce hourly or bihourly listings of the data on the digital magnetic tape. These listings are called primary computation sheets or "primaries" by the USGS. They are the only record of hourly or bihourly data available. The digital tapes from which the primaries are made are reused, thus destroying the only digital form of the data. Each primary sheet is carefully examined by a hydrologist and periods of erroneous, missing, or shifted data are identified. A second series of programs is then run to create a file of corrected data. The corrected files are then daily averaged and the results stored in the USGS's backfile library of daily values. The daily values are published each year on a state-by-state basis.

Obtaining hourly data from USGS thus is a matter of obtaining copies of the primary computation sheets. No software is maintained by USGS to provide the information in magnetic-tape form. Again, this is because the digital tapes on which the information from the paper tapes is copied are not saved. In general, it is not too difficult to obtain copies of the sheets. A district office is maintained in almost every state. The district chief will usually direct an interested user to the correct person to talk to. Occasionally reluctance is shown because the data are in raw form and must be interpreted with caution.

For this study, the primary sheets were obtained for 22 of the 30 USGS sites that showed positive correlation with rain or flow. For various reasons hourly data could not be obtained at the remaining eight sites. In most cases, the problem was inability to obtain the primary sheets. A number of older stations still record data on strip charts. These are not converted to digital form. In a very small number of instances the District Chief of a particular state would not release the primaries because of alleged deficiencies in the data. Emphasis was placed on obtaining periods of hourly data during June, July, August, and September. In addition to the primary sheets, appropriate rating curves were obtained for use in converting the stage data to discharge. Primary sheets report hourly stage instead of hourly flow.

Recovering useful data from the primary sheets requires a great deal of hand work. This was minimized for this study by developing a flexible plotting and analysis sequence for a desktop calculator. First, a program was developed which created digital magnetic-tape cartridge files. Each day of data of a particular kind (stage, DO, rainfall, or temperature) was entered as a separate tape file. Files were created only for periods when all four types of data were available simultaneously. Next, a processor and plotting program was developed. This program reads the files of data, applies the rating curve to the stage data to obtain flow, calculates the saturation DO level, and plots the results, including rainfall. The program contains shift table capability so that the stage datum can be corrected just as is done by USGS. The program allows periods from a single day up to one month to be studied.

A one-month period of hourly data for the Scioto River at Chillicothe, Ohio, is illustrated in Figure 5. A portion of the plot of 1972 daily data which contains the month is illustrated in Figure 6. These two plots are fairly typical of the hourly analysis procedure. The correspondence between descreasing DO and increased flow is fairly evident in Figure 6. The upper line in the figure is the observed daily minimum DO level, the lower line is the mean daily discharge. A decrease in the DO level can be seen in almost all instances when the flow increases. The period from day 215 to day 245 was selected as typical. Figure 5 provides a highly detailed hourly look at this same time period. The upper graph in Figure 5 illustrates the behavior of the absolute DO level. Daily fluctuations of approximately 4.0 mg/l were common before the rainfall and subsequent runoff event. The upper line in the DO graph is the saturation level based on the hourly water temperature. Note periods of super-

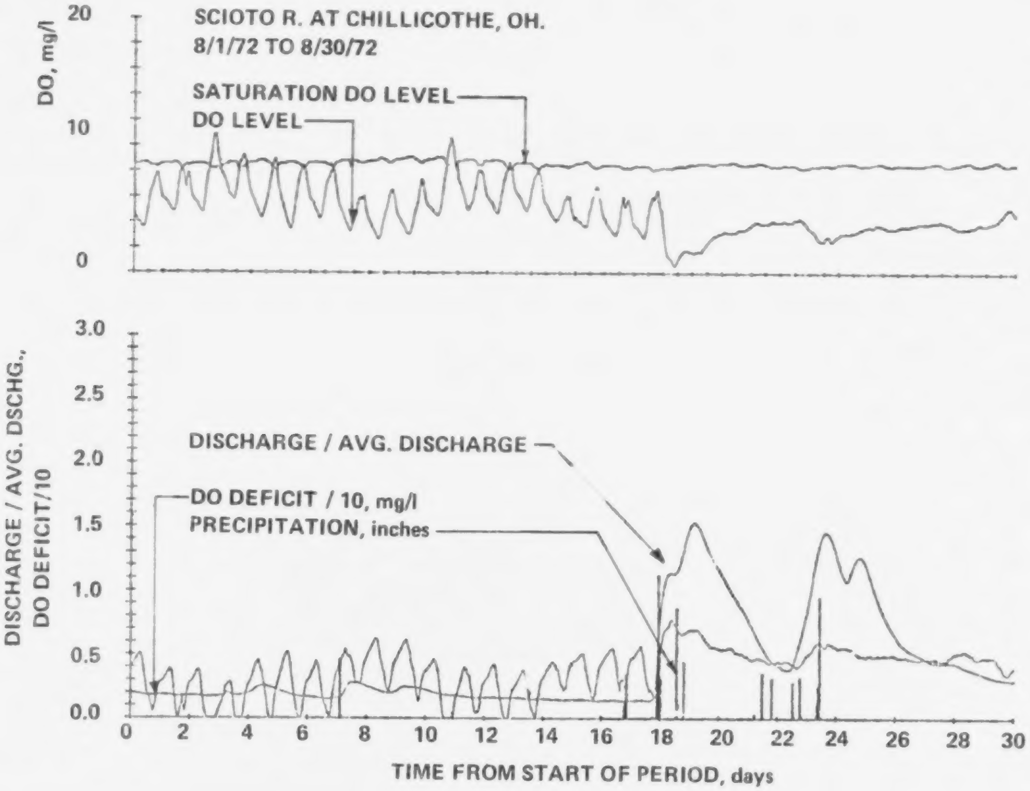


Figure 5. One month of hourly data for the Scioto River at Chillicothe, OH.

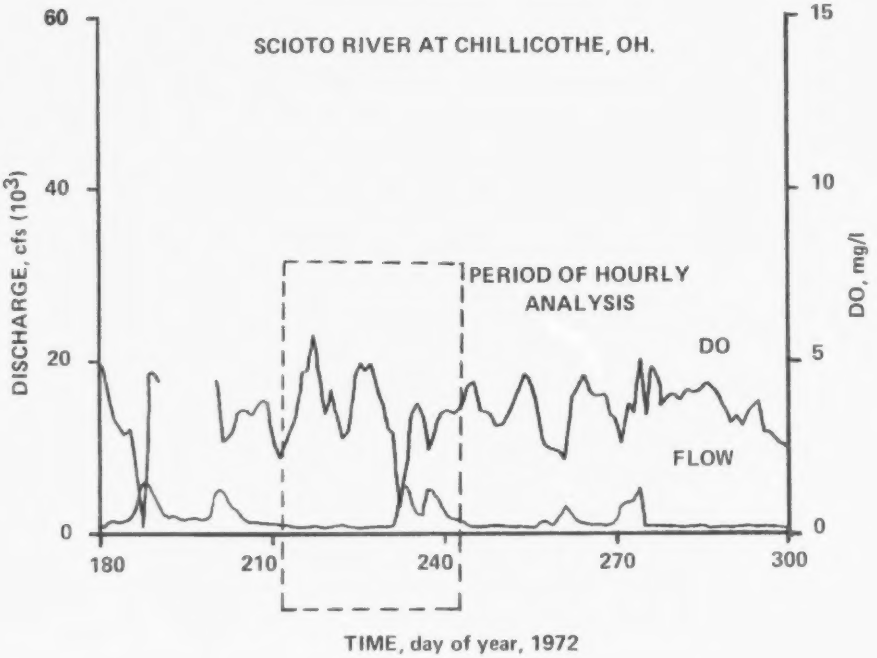


Figure 6. Hourly data for one-month period, Scioto River at Chillicothe, OH.

saturation occurring on days 3 and 11. Also note that the DO level falls below 2.0 mg/l and remains there for three days beginning at day 18. This precisely coincides with the peak of the flow hydrograph in the lower graph. The lower graph in Figure 5 illustrates the behavior of the flow, rainfall, and DO deficit. The flow has been plotted as discharge divided by averge discahrge for the period. This was simply a convenience to avoid rescaling every graph. The shape of the hydrograph is preserved and no useful information is lost. The DO deficit level is the difference between the upper and lower lines in the upper graph of Figure 5. This was included in the lower graph to aid in seeing the coincidence between a change in the behavior of the DO level and the change in flow. Rainfall amounts are plotted as histograms. The period of greater than average DO deficit that occurs during the time of higher-than-average flow can clearly be seen extending from day 18 to day 30. There is a clear correspondence between the rainfall events and the increases in flow.

Further discussion of the hourly data plots is included in Section 8. Additionally daily and hourly plots are included in Appendix D.

SECTION 8

ASSESSMENT OF EXTENT AND CAUSES OF PROBLEM

GENERAL CONSIDERATIONS

This section of the report presents an analysis of the findings. A very large number of data have been examined in various ways. The purpose of this final section is to determine what has been learned.

This section is divided into five subsections. Each subsection is designed to answer a question or several related questions concerning the correlation between DO deficit and urban runoff. These questions are as follows:

- Is there a correlation between the presence of urban runoff and DO deficits? If so, what is the nature of the correlation and are water quality standards violated when the correlation is present?
- Is the problem national in scope?
- What are the causes of the problem?
- Where is the problem worth studying further?
- What should be studied and how?

THE EXISTENCE OF A CORRELATION, ITS NATURE AND SEVERITY

Daily Correlation Analysis

The answer to the first part of the first question (Is there a correlation between periods of higher-than-average DO deficit and storm runoff?) is an unqualified "yes." Some general statistics and results will now be presented to support this conclusion.

Attempts were made to run daily correlation analysis using either flow or rainfall or both on 104 stations. These included USGS, STORET, and WDNR data. Of these, 83 had sufficient data or data that could be economically analyzed to produce results.

These included 55 USGS monitors, 17 STORET monitors, and 11 WDNR monitors.

Of the USGS monitors, 19 exhibited a 60 percent or greater probability of low DO at times of high flow. Eighteen exhibited a 60 percent or greater probability of low DO on days with rainfall. Eight of the stations correlated with both flow and rainfall. The total number of stations exhibiting either type correlation was 30. Of the 17 STORET monitors, three exhibited a 60 percent or greater probability of low DO at times of high flow. Of the 11 WDNR monitors, three exhibited the 60 percent or greater probability.

Out of 104 candidates for daily analysis, 35 (19 USGS flow +18 USGS rain -8 USGS overlap +3 STORET +3 WDNR) gave positive results in the correlation analysis. Twenty-one of the monitors could not be correlated because of problems in obtaining or using data. Thus, 42 percent of the monitors successfully examined, 34 percent of the likely candidates, gave positive correlation results. For discussion purposes, it will be assumed that four monitors in 10 placed near an urban area might indicate low DO at times of storm runoff. That is, a correspondence between lower-than-average DO and higher than average flow or rainfall can be identified. This does not mean that water quality standards are always violated.

An interesting question can be raised concerning the presence of a correlation at a given station: What is the implication of finding a correlation in only one or two of the years examined? Only general comments can be offered in answer. One problem comes from the statistical problem of defining a correlation in the first place. Recall that this was defined as a 60 percent probability of DO lower than the seven-day average on a day with flow or rainfall higher than the seven-day average. One can easily question the 60 percent cutoff level even though this has statistical significance. For instance, the Little Miami River near Spring Valley, Ohio, monitor showed strong correlation (65 and 67 percent) with flow in two of the five years examined. Two additional years had 58 and 59 percent probabilities. Should these years be counted as "correlated"? Examination of the daily DO and flow plots indicate that there are certainly times when the DO decreases on days with increased flow. A second problem in determining the presence or absence of a correlation comes from physical reality. Since the cause of the DO depressions is not known, it is not possible to say why a correlation is present one year and not the next. If the cause was sewage treatment plant overflow, perhaps a new plant was added. If the cause depends on time between storms for pollutant accumulation, then perhaps one year was wetter than the next. The answer to these questions will have to come from further research.

Nature of the Correlation

The second part of the first question concerned the nature of the correlation. When hourly data from sites with strong correlations were examined, similar DO records were found at sites with widely different physical settings. Data from the Scioto River at Chillicothe, Ohio, were presented earlier. Data from the Little Miami River near Spring Valley, Ohio, are reproduced from Appendix A in Figure 7.

The three-day period prior to the storm event (Figure 7) is characterized by fairly large diurnal cycles in the DO level, 4 to 5 mg/l is not unusual. Periods of supersaturation are often indicated. These are clearly visible at the Little Miami station. There is some question, of course, whether these periods are real or a monitor malfunction. Conversations with the USGS office in Columbus, Ohio, indicate that periods of supersaturation, due to algal growth, are common. The precipitation responsible for the rise in flow is visible just prior to the hydrograph along the bottom axis. Approximately six hours elapsed from the time of the rainfall to the beginning of the flow change. Approximately two inches of rainfall fell at Dayton for the several small events shown. As the flow increases, the diurnal cycles in the DO record disappear. This may be due to increased turbidity and depth cutting off the sunlight to the aquatic plant life at times of high flow. At the time of peak flow a deficit level 40 percent higher than the maximum achieved during a nonhigh-flow diurnal cycle is reached. This percentage increase at other sites with correlations varied from zero to 50 percent. In the case of the Little Miami, the peak deficit during diurnal cycles was 2.5 to 2.6 mg/l. At peak flow, the deficit reached 3.5 mg/l and the absolute DO level reached 5 mg/l.

The correlation between the DO deficit and the flow is very obvious in the lower graph. Beginning at the seventh day, seven small events follow in which the deficit curve mimics the flow hydrograph almost exactly. There is roughly a six-hour lag between the time the flow begins to increase and the time the deficit begins to increase.

The effect of the storm flow on the DO level is quite long lasting. Note, that on the Little Miami the DO has not returned to the diurnal cyclic behavior in 17 days. The DO depression caused by the large flow hydrograph that began on day 3 would probably have only lasted four to six days if it had not been followed by the smaller events on days 7, 10, and 13. This behavior is typical of all the sites with pronounced correlation. Sites at which a single hydrograph peak was examined usually recovered in three to five days.

This long-term effect gives added validity to the daily analysis procedure. If the DO depressions only lasted a few

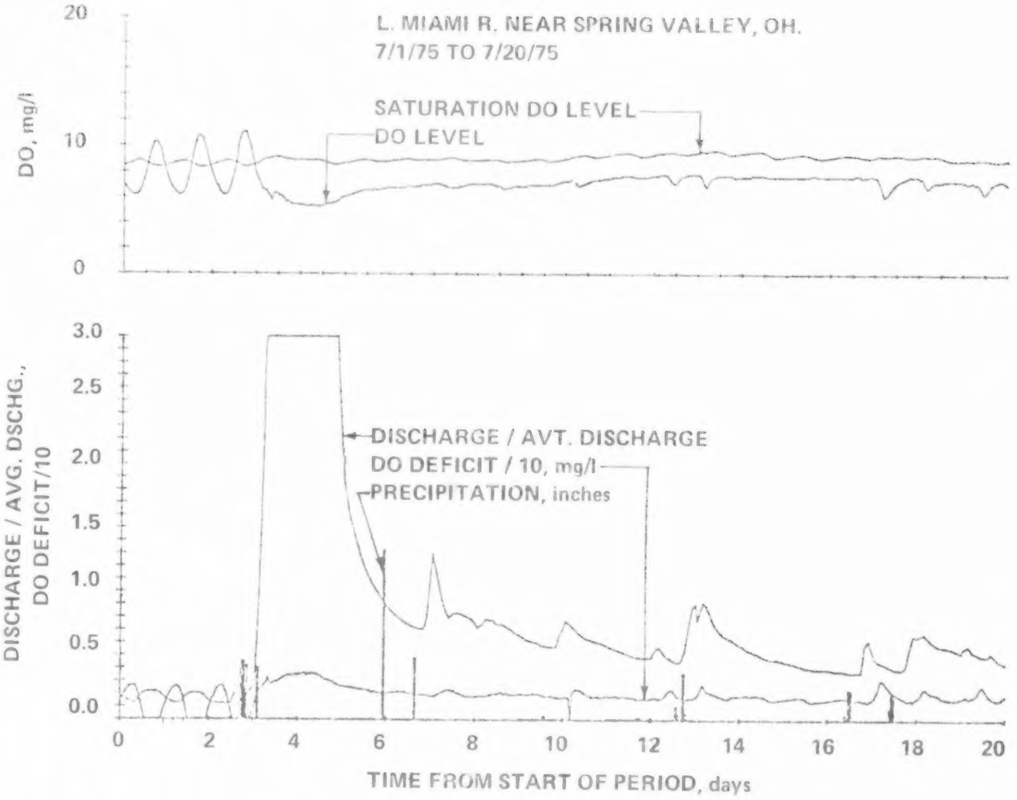


Figure 7. DO/flow correlation on the Little Miami River near Spring Valley, OH.

hours after storm events, it would not be possible to detect them using daily average data.

Severity of Problem

The final part of the first question concerned the severity of the DO deficits associated with urban runoff. The fact that the DO decreases at times of storm runoff is scientifically of interest. However, if the level does not consistently decrease below prescribed standards, no "problem" exists.

Water quality standards were mentioned in the introduction. There is no uniform standard for the entire country. Generally, for a warm-water system containing fish, other aquatic life, and wildlife, a level of 5 mg/l is recommended (Thomann (2)). The ORSANCO recommends that DO levels not drop below 5 mg/l for more than eight hours a day or below 3.0 mg/l at any time. The EPA standards recommend that DO not drop below 2.0 mg/l for more than four hours or below 3.0 mg/l for three days. The hourly DO data in Appendix D were examined carefully and compared to these standards.

The first standard used to examine the hourly data was simply 5.0 mg/l. This standard appears so frequently in the literature that the writers felt it was worthwhile to identify those sites that would not meet it. While 5.0 mg/l is not a severe water quality problem, it is certainly poor water quality. Eleven monitor sites on nine rivers had hourly DO levels that fell to 5.0 mg/l or below. These 11 monitor sites are identified in TABLE 14. Also listed in the table are the minimum observed DO level and the time (hours) that the DO remained below 5.0 mg/l because of the change in flow.

The next standard used to examine the hourly data was the EPA recommended standard. Six monitor sites on five rivers had hourly DO levels that violated the EPA standard. These six sites are listed in TABLE 15. Also listed in the table are the minimum observed DO level, the approximate DO level before the runoff event, and the time the DO remained below 2.0 mg/l.

The final examination of the data with respect to standards was to determine how many additional monitor sites would show EPA standard violations if the monitor were more appropriately located. Minimum observed values were reduced by the difference between the Streeter-Phelps predicted minimum value and the Streeter-Phelps predicted value at the monitor site. Four additional monitor sites would probably show EPA standard violations if properly located. These are listed in TABLE 16. Also listed for each site are the minimum observed DO level, the Streeter-Phelps correction, and the predicted minimum for a properly located monitor. Hourly data were not available at two of the four sites listed. The observed values were taken from plots of

TABLE 14. MONITOR SITES AT WHICH DO LEVELS BELOW 5.0 mg/l WERE OBSERVED

No.	Monitor name	Minimum observed DO level, mg/l	Length of time below 5.0 mg/l, hours
1	N. Nashua R. near Lancaster, MA.	1.8	8
2	Wilsons Cr. near Springfield, MO.	0.0	84
3	Cuyahoga R. at Independence, OH.	4.9	3
4	Cuyahoga R. at Old Portage, OH.	1.9	4
5	Little Miami R. at Spring Valley, OH.	5.0	1 or less
6	Mad R. near Dayton, OH.	4.9	1 or less
7	Sandusky R. near Upper Sandusky, OH.	1.5	240+
8	Scioto R. at Chillicothe, OH.	0.9	168
9	Schuylkill R. at Philadelphia, PA.	3.0	72
10	Trinity R. below Dallas, TX.	0.9	All the time
11	Trinity R. near Rosser, TX.	0.0	All the time

TABLE 15. MONITOR SITES AT WHICH EPA DO STANDARDS WERE NOT MET DURING RUNOFF EVENTS

No.	Monitor name	Minimum DO level mg/l	DO level before runoff, mg/l	Time DO remained below 2.0 mg/l, hours
1	N. Nashua R. near Lancaster, MA.	1.8	5-6	4
2	Wilsons Cr. near Springfield, MO.	0.0	6-10	9
3	Sandusky R. near Upper Sandusky, OH.	1.5	5-9	18
4	Scioto R. at Chillicothe, OH.	0.9	4-10	16
5	Trinity R. below Dallas, TX.	0.0	2-3	Much of the time (6-8 hr/event)
6	Trinity R. below Rosser, TX.	0.0	1-2	Much of the time (6-8 hr/event)

the daily minimum for years with positive correlation. One additional monitor site, the Little Miami River near Spring Valley, Ohio, monitor, would probably be included with those in TABLE 16 if the Streeter-Phelps analysis had been used there. The monitor is near the outskirts of Dayton. Experience with other sites indicates that if the monitor had been 30 to 40 miles further downstream, it might have sensed a greater deficit. Absolute DO levels of 5.0 mg/l were observed at the monitor's present location.

TABLE 16. MONITOR SITES WITH POTENTIAL FOR EPA STANDARD VIOLATIONS IF PROPERLY LOCATED

No.	Monitor name	Problem with location	Minimum observed DO level, mg/l	Streeter/Phelps correction, mg/l	Possible minimum DO level, mg/l
1	Cuyahoga R. at Independence, OH.	Too close to urban area	4.9	4.9	0.0
2	Cuyahoga R. at Old Portage, OH.	Too close to urban area	1.9	1.9	0.0
3	Mahoning R. at OH.-PA. State Line below Lowellville, OH.	Too close to urban area	0-1.5 (daily)	1.5	0.0
4	Maumee R. at Defiance, OH.	Too far from urban area	2.5-4.0 (daily)	4.0	0.0

Several other general observations were made from the hourly data concerning the severity of the problem. Three of the USGS sites examined were unusual. All showed strong correlation between flow and low DO but none were truly urban in character. Center Creek near Carterville, Missouri, for instance, is near a relatively small town in an isolated area. There is a good deal of strip mining near the monitor. The site on the Manasquan River near Squankum, New Jersey, was near a large federal munitions reservation and a few suburbs, but nothing truly urban. Much of the drainage appeared swampy. The site on the Little Miami River at Miamiville, Ohio, is in the far outskirts of Cincinnati and has no direct drainage from the city. Five of the sites examined on an hourly basis did not have water quality problems associated with urban runoff, at least concerning DO. However, some depression during storm events could usually be seen. These five sites are on the

- Ashtabula R. at Ashtabula, OH;
- Grand R. at Painsville, OH;
- Hocking R. at Athens, OH;
- Delaware R. at Chester, PA; and
- Lehigh R. at Easton, PA.

In summary, the question "Do severe (EPA standard) DO deficits occur downstream of urban areas due to urban runoff?" cannot be answered conclusively. There is definite evidence that decreases in DO levels occur downstream of a number of urban areas after rainfall or flow events. However, only six of the monitor sites examined for this study showed clear evidence of EPA water quality standard violations. For purposes of discussion, the following facts might be considered. A population of 104 monitor sites were considered for analysis. Data could only be obtained for 83 of these. Out of the 83, only some of the 55 USGS sites could be examined on an hourly basis. Of the 55 USGS sites, 29 showed positive correlation between either rainfall or flow events and low DO. Of these 29, only 22 could be examined on an hourly basis. Eleven of the 22 could not meet a 5.0 mg/l DO standard and six could not meet the lesser EPA standard of 2.0 mg/l for four hours. When poor monitor location is accounted for using the Streeter-Phelps technique, a total of 10 sites might not meet the EPA standard. If it is assumed that the group of monitors actually examined closely (22) contains the same percentage of monitors with water quality violations as the candidate group (104), the following is obtained. Including Streeter-Phelps sites, (13/29) of the 42 percent ((29+3+3)/83) of all monitors that might be correlated, or 19 percent of the candidate monitors, might not meet a 5.0-mg/l standard. (Eight/22) of the 42 percent, or 15 percent, might not meet the EPA standard of 2.0 mg/l for four hours. The frequency of these violations would appear to be fairly low. No exact figures can be given because programs were not developed to address this question. Three to five violations per year at a site with a strong correlation might be a reasonable guess. This question of frequency should probably be the subject of further investigation.

In fairness, it must be pointed out that the water quality at sites with EPA standard violations is marginal at all times. Storm events merely push the level down further. General improvements in water quality at all the critical (EPA standard) sites would help alleviate the problem. For example, the mainstream of the Delaware River below Trenton, New Jersey, consistently shows a correlation between DO deficit and flow events. The DO levels are high enough and the river big enough to absorb the effect without standard violations. Note that it is not possible from this study to define how the water quality might be improved at critical sites. Further investigation would be required to determine why quality is poor.

SCOPE OF THE PROBLEM

The question of whether urban runoff caused DO deficits is a national problem is difficult to answer. One item to consider is the geographic coverage of this study.

The USGS data base maintained at the USGS National Headquarters contains records for 150 water quality monitors. These monitors are located in 30 of the 48 conterminous states, i.e., 63 percent coverage. The distribution of states containing monitors is highly nonuniform. Thirteen states are east of the Mississippi River and 17 are west. Only 47 of the 150 monitors are in western states. If the dividing line between east and west is considered as the western boundaries of Louisiana, Arkansas, Iowa, and Minnesota, the distribution becomes even more unbalanced. Only 19 monitors are then located in the west.

The distribution of monitor by state is highly nonuniform also. The top five monitoring states and the numbers of monitors for USGS are:

- Ohio, 32;
- New Jersey, 14;
- Pennsylvania, 13;
- Louisiana, 11; and
- South Carolina, 10.

These five states contain over half of all USGS monitors. Ohio alone contains over 20 percent.

The STORET data base contains over 1000 monitor records. It added, however, only three additional states to the geographic coverage. Most of the STORET monitors applicable to this study are located in North Carolina along the Neuse River.

The major monitoring networks that contributed to this study are not designed to provide uniform geographic coverage. They are heavily biased toward the northeast, with a fair amount of coverage in the south. Some investigation of whether the networks are adequate to detect a national problem is in order.

It is reasonable to assume that the more water quality monitors are present in a state, the more likely any existing DO problems would be found. The data used in this study were examined by state to determine the number of sites with water quality standards violations versus the number of monitors present. The number of correlations found versus the number of monitors was also considered. The results are given in TABLE 17. Listed are states with violations, the rank of the state in terms of number of monitors, and the type of violation (5.0 mg/l or EPA, 2.0 mg/l for four hours). Streeter-Phelps sites are included in the totals. The sites counted in the visible correlation column are those where DO depressions of any size could be seen at the time of storm events. No consideration was given to standards.

TABLE 17. PROBLEM SITES PER STATE VERSUS NUMBER OF MONITORS PER STATE

State	No. of USGS monitors in state	Rank in terms of monitors	No. of sites with visible correlations	No. of sites with 5.0 mg/l standard violations	No. of sites with EPA standard violations
Ohio	32	1	10	8	6
Massachusetts	9	6	3	1	1
Missouri	10	5	3	1	1
Texas	3	10	2	2	2
New Jersey	14	2	2	0	0
Pennsylvania	13	3	1	1	0
Oregon	1	Tie for 12	1	0	0

The probability of finding visible evidence of a correlation between low DO and runoff events appears to be one in three (number of correlations divided by number of monitors in state). The probability of finding a site where the 5.0-mg/l standard is violated appears to be between one in 10 and one in four. The probability of finding an EPA standard violation is between one in 10 and one in five.

The writers feel that the geographic distribution of the nation's water quality monitoring network is not adequate to conclude anything on national scope of urban runoff related DO problems. The odds seem to indicate that if monitors were located in a Streeter-Phelps correct way, then one in three would show some evidence of a correlation between urban runoff and DO depression. Of those, one in 10 to one in four might indicate standards violations.

There is little other information on which to base an estimate of the national impact of urban runoff. Considerable time was spent trying to determine if any government agency kept statistics on the distribution of the nation's population along rivers. The U.S. Water Resources Council is considering such an effort but to date has not implemented a project. If results from such a project were available, it might be possible to estimate the number of potential stream miles affected using the Streeter-Phelps technique. Even this would not be conclusive because there is no well-defined relationship between size of the urban area and the presence of correlations or standards violations. This is discussed in the following subsection. The monitoring network is also not adequate to extrapolate the problem from one area of the country to another.

POSSIBLE CAUSES OF PROBLEM

The Scope of Work did not call for a determination of the cause of specific problems. It did call for considerations of the percentage of contributing area when selecting monitors for inclusion in the study. The percentage of urban area was also to be considered when stating that a low-DO condition was related to the presence of urban area. This will be discussed along with some other possible contributing factors.

It is intuitively inviting to assume that the larger the percentage of a drainage basin that is urban, the more likely it should be that a low-DO runoff correlation would exist. This did not prove to be the case for the data examined here. Figure 8 illustrates the nonrelation between the probability of a greater-than-average DO deficit during higher-than-average flow and the percentage of urban drainage. Data for this figure were taken from Appendix D for most of the 29 USGS sites that showed positive correlation between flow or rainfall and low DO. The percentage of urban drainage ranges from less than one to more than 80.

Several other relationships were investigated in an effort to determine what effect the percentage of urban area has on the presence of a correlation. Equally discouraging results were obtained. For instance, a regression was run using the mean probability of low DO at times of high flow as one parameter and the estimate of urban storm flow from the Streeter-Phelps analysis divided by the mean low flow at the station as the second variable. The idea was that if the volume of urban storm runoff was high compared to the normal stream flow, then the influence of the runoff would be greater and, hence, the correlation would be greater. Many streams are regulated and the percentage of drainage is no longer a measure of the percentage of flow that may be contributed. The results looked encouraging but statistically the correlation coefficient was 0.002. Regressions were also run using estimated urban flow divided by average flow as one parameter and both maximum and mean probability of low DO at times of high flow as the second parameter. These were also unsuccessful. The problem is too complex to study using simple relations.

As stated earlier, it was not part of the Scope of Work to precisely identify the cause of each problem. However, it is worthwhile to examine some other possible causes since the obvious urban area percentage proved discouraging. These are the types of things that should be studied in order to better understand the problem.

The urban areas with strong correlations are of many sizes, covering a fairly large range. The population of Leominster, Massachusetts, is approximately 33,000, while the population of

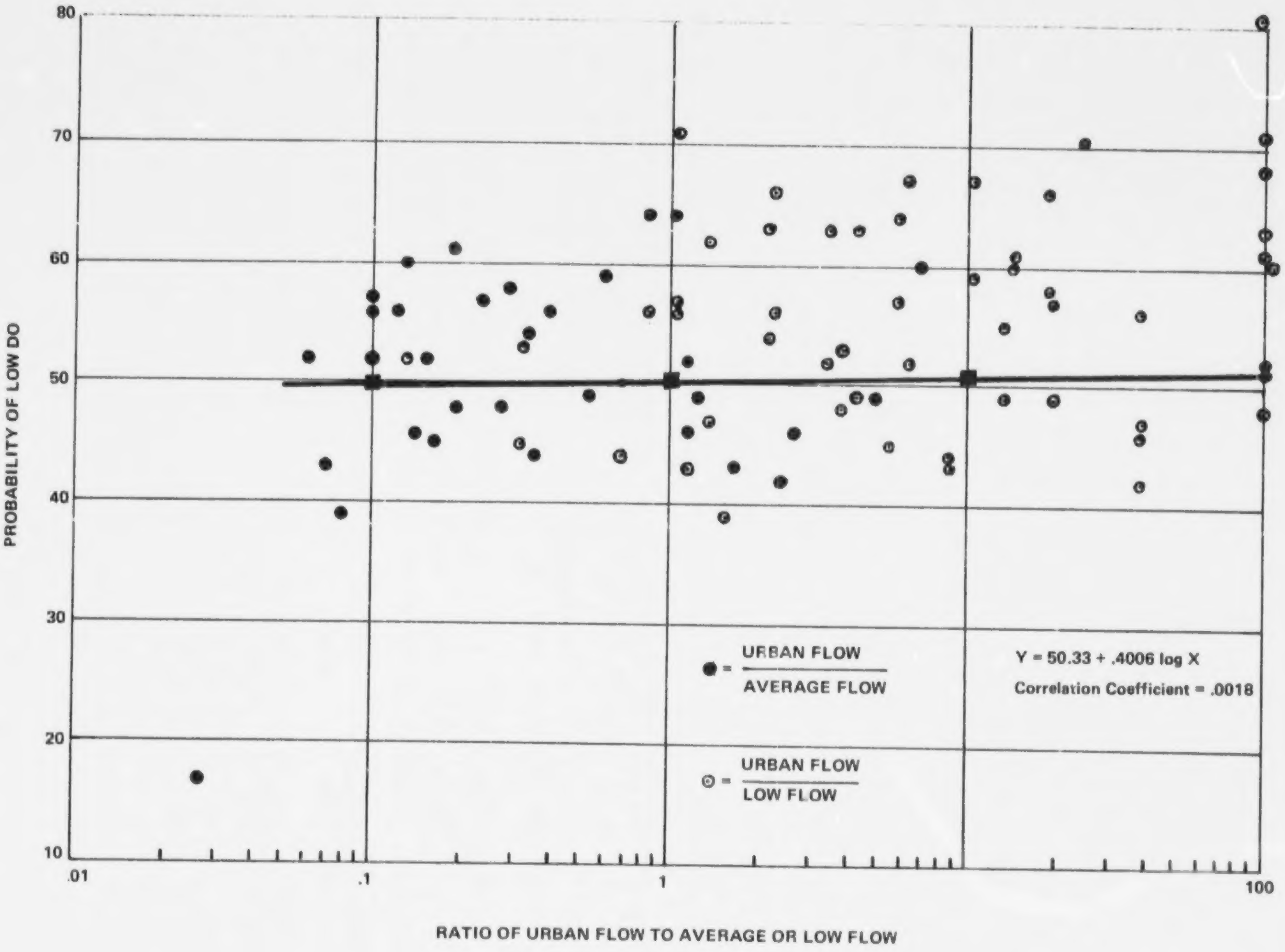


Figure 8. Probability of low DO at high flow versus percentage of urban area.

Akron, Ohio (Cuyahoga River at Independence monitor), is nearly three quarters of a million. Several of the monitor sites with poor monitor location in a Streeter-Phelps sense were near urban areas of 20,000.

Close study of the sites with strong correlations did not reveal any notable common characteristics. For instance, the Mahoning River at the Ohio-Pennsylvania state line below Lowellville monitor is just downstream of Youngstown, Ohio. Youngstown is in a very hilly country. A large concentration of steel mills and several sewage treatment plants are located along the river. The monitor is located on the fringe of the urban development. The monitor on the Sandusky River near Upper Sandusky, Ohio, is in a fairly rural setting some 30 miles downstream of Bucyrus, Ohio. Bucyrus is a city of 30,000.

Proximity to sewage treatment facilities is a matter of some interest. In most cases, at least one treatment plant was located upstream of the monitor site. Distances varied from less than one mile to 8 to 10 miles. The monitor on the Raritan River near South Bound Brook, New Jersey, had six treatment plants within five miles upstream. Reintrainment of oxygen-demanding materials in solids deposits downstream of outfalls could certainly be a factor at some locations. Combined sewer overflows could also be a factor. Quality and capacity of treatment facilities should also be considered. If significant quantities of sewage are bypassed during times of high flow, the impact on a receiving water could be significant. A high percentage of BOD removal still leaves significant quantities of BOD for high-volume facilities. The remainder must be oxidized by the stream in some way.

The hourly records examined did not show any "first flush" effect. The DO deficit increased in a smooth way and remained high for lengthy periods. This might indicate that for the cases examined the problem is not related to a buildup of material that is flushed rapidly away. The length of the deficit period points to sources of oxygen-demanding material that would continue throughout a storm event.

The type of activity carried out along the stream in the urban environment should certainly be investigated as a cause of wet weather DO deficits. Sewage treatment has already been mentioned. Certain types of industry continue to discharge treated waste. Gravel dredging and concrete mixing activities often concentrate along rivers. Each site has its own peculiarities.

SPECIFIC STUDY SITES

The data examined here indicate that water-quality violations associated with flow events can occur downstream of urban areas. The 5.0 mg/l and EPA (2.0 mg/l for four hours) standards are both violated. The frequency of such violations was not determined exactly, but no need for panic treatment appears to exist. There is, however, a need to understand the causes of the DO deficits observed here. An exact understanding of the causes can be used to prevent the frequency of occurrences from increasing. The purpose of this subsection is to identify and discuss those monitor sites that the writers feel are worthy of further investigation.

TABLE 18 identifies those monitor sites that are most likely to yield useful results from further study. Listed along with each site are the minimum observed DO level, the standard that was violated, and a short description of why the site was chosen. The sites are listed in the order of preference for study. Two monitor groups are identified. The first group is hydraulically simple sites; single streams with major urban areas present. The second group is complex sites with branched streams, several towns, and other factors--sites where more sophisticated analysis techniques and data collection will be required.

The first group contains five monitor sites. These are the Scioto River, near Chillicothe, Ohio; the Cuyahoga River at Old Portage and Independence, Ohio; the Mahoning River at the Ohio-Pennsylvania state line near Lowellville, Ohio; the Sandusky River near Upper Sandusky, Ohio; and the Little Miami River near Spring Valley, Ohio.

The Scioto River site is highly attractive. It has one of the most distinct correlations of any station examined on an hourly basis. The monitor is located fairly well in a Streeter-Phelps sense to detect the sag from Columbus, Ohio. The USGS is establishing a monitor at Circleville, which is halfway between Chillicothe and Columbus. An additional monitor called Scioto River at Shadeville is situated in Columbus. The Ohio USGS personnel are extremely cooperative and would probably be interested in collecting sediment or other supplementary data to examine this site. This is also an excellent choice for further study.

The Cuyahoga River flows southwestward, generally paralleling the southern shore of Lake Erie. It turns north at Akron, Ohio, joining the Little Cuyahoga, and flows through Cleveland into the lake. All of the flow from Akron is sensed by both monitor sites. The monitor at Independence is below the mouth of Tinkers Creek, which drains part of Cleveland and its suburbs. The Akron sewage treatment facilities lie between the two monitors. They are separated by roughly 13 miles. Sediment records are available at both sites. The Cuyahoga is famous for having caught fire in the early 1960. This, however, was in the industrial part of Cleveland, which is below both monitors. There should be considerable other data available here.

TABLE 18. SITES RECOMMENDED FOR FURTHER STUDY

Site classification	Monitor normal	Min. DO level, mg/l	Standard violated	Reason for recommendation
Simple	Scioto R. near Chillicothe, OH.	0.9	EPA	Clear correlation in hourly data; clearly defined urban area and hydraulics; potential for cooperation with USGS
	Cuyahoga R. at Independence and Old Portage, OH.	1.9, 4.9	5.0 mg/l, potential EPA	Sediment data available; clearly defined urban area; national reputation for poor quality.
	Mahoning R. at OH.-PA. State Line below Lowellville, OH.	0-1.5	Potential EPA based on daily	Large, clearly defined urban area draining to single stream; good example of heavily industralized flood plain.
	Sandusky R. near Upper Sandusky, OH.	1.5	EPA	Well located to sense runoff from Bucyrus; straightforward hydraulics.
	Little Miami R. near Spring Valley, OH.	5.0	5.0 mg/l, potential EPA	Close to outskirts of Dayton; simple hydraulics; clear DO depression with storm events.
Complex	North Nashua R. near Lancaster, MA.	1.8	EPA	Significant problem; two distinct urban areas.
	Schuylkill R. at Philadelphia, PA.	3.0	5.0 mg/l	Major urban area; empties into Delaware R.
	Trinity R. below Dallas, TX.	0.0	EPA	Biggest urban area of any site; worst water quality.
	Wilsons Cr. near Springfield, MO.	0.0	EPA	
	Wilsons Cr. near Battlefield, MO.	–		Clear correlation; second worst water quality of any monitor site.
	James R. near Boaz, MO.	–		

The remaining three sites in the first group are all equally attractive. The Mahoning River site is just below Youngstown, Ohio, an industrial city of half a million. The Sandusky River monitor is in a excellent position to study runoff from Bucyrus, Ohio, a city of 20,000. The Little Miami River site receives the runoff from Dayton and Xenia, Ohio. All three are single streams draining well-defined urban areas with no other significant urban area upstream.

The second group of sites contains six monitor sites and four stream systems. These are given in roughly the order of preference for study. All are interesting, but they would require extensive investment in complex models and supportive data collection. They are the North Nashua River near Lancaster, Massachusetts; the Schuylkill River at Philadelphia, Pennsylvania; the Trinity River below Dallas, Texas; Wilsons Creek near Springfield and Battlefield, Missouri; and the James River near Boaz, Missouri.

The North Nashua River site is complicated by two distinct urban areas, Fitchburg and Leominster. Each are cities of roughly 35,000. The monitor and flow gages are separated by several miles and a lake dilutes the stream below the monitor.

The Schuylkill River site is in the heart of industrial Philadelphia, just upstream from the junction with the Delaware River. It may be partially tidally affected. There is no question of it being an urban site, but only a small reach of river is available for study before reaching the Delaware.

The Trinity River below Dallas, Texas, has the worst water quality observed anywhere during the study. Six lakes regulate the flow and in the summer the stream is mostly treated sewage effluent. The DO falls to zero at a monitor 40 miles downstream of Dallas during storm events. The site is discouraging just from the physical size of the contributing urban area, over 700 square miles.

The Wilsons Creek and James River sites in Missouri also have very bad water quality. These sites have the highest percentage urban contributing area in the study, 85 percent. The two Wilsons Creek monitors would be interesting to study, but the flow in the James is regulated by a lake that catches some of the runoff from Springfield. A number of small creeks feed the runoff from Springfield into Wilsons Creek.

RECOMMENDATIONS FOR STUDY PROCEDURES

Two types of further study would be worthwhile. The first is a general site survey. The second is a specific study of detailed site(s).

The general survey study would not require a great deal of resources. The study procedure would be to visit each of the monitor sites where a strong correlation has been identified. Characteristics of the stream and the land use along it would be identified. Local agencies would be visited to determine sewage treatment practices, industrial practices, and other activities impacting water quality. The study objective would be to develop a general picture of the places where the problem has been observed. A study of this type could more accurately locate sewage outfalls, combined sewer overflow locations, industrial waste deposits and other things not part of the present study.

The detailed site-specific study (studies) should be directed toward understanding exactly what happens at one or several locations where strong correlations have been observed. This will require considerably more effort. Ideally, a well-designed data collection program should be undertaken to support a mathematical model. The study should be undertaken in three parts. First, the necessary information to build an accurate model of the receiving water flow should be obtained. This will include stage records, cross-sections, and tributary and mainstream discharge data. The second step contains two substeps. First, an accurate unsteady flow model should be set up and calibrated. Steady-flow modeling should not even be considered. The problem is associated with unsteady flow and should be studied with the appropriate models. The technology is available and not overly expensive. Second, the unsteady flow model should be coupled to a conservative mass transport model. If at all possible, this should be verified by conducting a dye study during a storm event. This procedure positively guarantees a model that will produce meaningful transport predictions.

The final step is to model the transport of nonconservative constituents such as BOD and DO. No data should be collected until the conservative transport model has been verified. It should then be modified to handle the appropriate constituents and used to simulate expected conditions during several storm events. Best guesses are used for all unknown coefficients. All data sampling should be geared to define those receiving water reaches and at those times the model indicates as critical or of most interest. This minimizes sample cost and maximizes model accuracy when calibration is undertaken. Transport in transient flow is not easy to second guess. This has been amply demonstrated by Jobson and Keefer (11) on the Chattanoochee River. Only an accurate process model can tell the investigator when and where to look.

After the necessary data are collected for the constituents of most interest, the model can be calibrated for these. If this proves impossible, further data collection and model modification can be undertaken. Since it will be known that the model accurately predicts conservative transport, any errors in the nonconservative transport have to be due to inadequately defined coefficients or processes that were not considered. By carefully proceeding to add capability to the model (e.g., benthic sediment, chemical oxygen demand, and others), the exact cause of the DO-deficit/high-flow correlation can be identified.

It is highly unlikely that adequate data for a modeling effort of the type exists. Attempting such a study with existing monitor records and randomly collected water quality samples is probably a waste of time.

The writers would strongly recommend the Scioto River between Columbus and Chillicothe, Ohio, for a study of this type. This would provide an excellent site and the maximum opportunity for cooperation with USGS. As a second choice, the Cuyahoga River between Akron and Cleveland, Ohio, would be good. There are some sediment records that may be helpful and the hydraulic conditions are simple to model. This is also true of the Scioto River.

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APPENDIX A

WATER QUALITY DATA COLLECTION AGENCIES

This appendix contains a complete listing of all the agencies that collect water quality data as reported by the USGS Office of Water Data Coordination (OWDC). The agencies and their identification codes are listed according to the regions described in Section 5 of the report.

REGION 1

FEDERAL AGENCIES

CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
ERD	Energy Research and Development Administration
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)

CANADA

WQB	Environment Canada, Water Quality Branch
WSC	Environment Canada, Water Resources Branch

NON-FEDERAL AGENCIES

	Connecticut
D00	Environmental Health Service Division, State Department of Health
D01	The Water Bureau of the Metropolitan District, Hartford
D02	Bridgeport Hydraulic Company
D05	Connecticut Department of Environmental Protection
	New York
P50	New York State Department of Environmental Conservation

REGION 2

FEDERAL AGENCIES

AHS	Army Health Services Command (Army)
CE	Corps of Engineers (Army)
ERD	Energy Research and Development Administration
EPA	Environmental Protection Agency
GS	Geological Survey (Interior)
MC	Marine Corps (Navy)
MFS	National Marine Fisheries Service (Commerce)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)

CANADA

WQB	Environment Canada, Water Quality Branch
WSC	Environment Canada, Water Resources Branch

NON-FEDERAL AGENCIES

Delaware

D50	Delaware Geological Survey

Maryland

D51	Baltimore County Health Department
D52	City of Baltimore, Water Supply Treatment and Pumping Division

District of Columbia

D53	Department of Sanitary Engineering
D54	Department of Environmental Health Administration

New Jersey

050	Passaic Valley Water Commission
051	New Jersey State Department of Environmental Protection
052	North Jersey District Water Supply Commission
054	Delaware River Joint Toll Bridge Commission

New York

P50	New York State Department of Environmental Conservation

Pennsylvania

S50	Pennsylvania Department of Environmental Resources

Virginia

W00	State Water Control Board

West Virginia

X50	West Virginia Department of Natural Resources
X51	West Virginia Department of Health

REGION 3

FEDERAL AGENCIES

AHS	Army Health Services Command (Army)
CE	Corps of Engineers (Army)
ERD	Energy Research and Development Administration
EPA	Environmental Protection Agency
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
MC	Marine Corps (Navy)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)

NON-FEDERAL AGENCIES

Alabama

A04	Alabama Water Improvement Commission

Florida

E00	Hollywood Reclamation District
E01	Hillsborough County Health Department
E02	Manatee County Health Department
E03	Central and Southern Florida Flood Control District
E17	State of Florida Department of Pollution Control
E21	Hillsborough County Environmental Protection Commission

Georgia

E50	Savannah Department of Water and Sewage
E51	Thomasville Water and Light Department
E52	Valdosta Water and Sewer Department
E53	Water Works, City of Gainesville
E54	Rome City Manager
E55	Water Works, City of Griffin
E56	Board of Water Commissioners, City of Macon
E57	Atlanta Water Works
E58	Columbus Water Works
E60	Georgia Department of Natural Resources

Louisiana

I51	Louisiana State Department of Health
I59	Louisiana Wildlife and Fisheries Commission

Mississippi

L51	City of Jackson Water Works
L52	Pearl River Valley Water Supply District
L53	City of Meridian Water and Sewer Dept.
L54	City of Columbus Light and Water Dept.
L55	Mississippi State Board of Health

North Carolina

Q00	North Carolina Department of Human Resources
Q01	North Carolina Department of Natural and Economic Resources

South Carolina

T50	Agricultural Engineering Department, Clemson University
T51	Greenville Water System
T52	Spartanburg Water Works
T53	South Carolina Department of Health and Environmental Control

Tennessee

U52	Cleveland Water System

Virginia

W00	State Water Control Board

REGION 4

FEDERAL AGENCIES

CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
ERD	Energy Research and Development Administration
FS	Forest Service (Agriculture)
FWS	Fish and Wildlife Service (Interior)
GLB	Great Lakes Basin Commission
GS	Geological Survey (Interior)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)

CANADA

WQB	Environment Canada, Water Quality Branch
WSC	Environment Canada, Water Resources Branch

NON-FEDERAL AGENCIES

Illinois

G00	Illinois Department of Public Health
G01	Metropolitan Sanitary District of Greater Chicago
G03	Illinois Department of Public Works and Buildings

Indiana

G50	Indiana State Board of Health

Michigan

K50	Michigan Department of Natural Resources

Minnesota

L02	Minnesota Department of Natural Resources
L06	Water, Gas and Sewage Treatment Department, City of Duluth
L07	Minnesota Ore Operations, USS Corp.
L09	Minnesota Power and Light Company
L11	Minnesota Pollution Control Agency

New York

P50	New York State Department of Environmental Conservation

Ohio

R03	Ohio Environmental Protection Agency

Pennsylvania

S50	Pennsylvania Department of Environmental Resources

Wisconsin

Y00	Wisconsin Department of Natural Resources
Y05	Wisconsin Michigan Power Company

REGION 5

FEDERAL AGENCIES

AHS	Army Health Services Command (Army)
CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
ERD	Energy Research and Development Administration
FS	Forest Service (Agriculture)
FWS	Fish and Wildlife Service (Interior)
GS	Geological Survey (Interior)
NWS	National Weather Service (Commerce)
TVA	Tennessee Valley Authority

NON-FEDERAL AGENCIES

	Illinois
G00	Illinois Department of Public Health
G02	Illinois Department of Registration and Education
G03	Illinois Department of Public Works and Buildings
	Indiana
G50	Indiana State Board of Health
	Kentucky
I00	Kentucky Department for Human Resources
I01	Kentucky Department for Natural Resources and Environmental Protection
	New York
P50	New York State Department of Environmental Conservation
	North Carolina
Q01	North Carolina Department of Natural and Economic Resources
	Ohio
R00	Ohio Department of Natural Resources
R01	The Miami Conservancy District
R02	Ohio River Valley Water Sanitation Commission
R03	Ohio Environmental Protection Agency
	Pennsylvania
S50	Pennsylvania Department of Environmental Resources
	South Carolina
T53	South Carolina Department of Health and Environmental Control
	Tennessee
U50	Tennessee Wildlife Resources Agency
U51	Tennessee Department of Public Health
	Virginia
W00	State Water Control Board
	West Virginia
X50	West Virginia Department of Natural Resources
X51	West Virginia Department of Health

REGION 6

FEDERAL AGENCIES

EPA	Environmental Protection Agency
ERD	Energy Research and Development Administration
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
NWS	National Weather Service (Commerce)
TVA	Tennessee Valley Authority

NON-FEDERAL AGENCIES

	Alabama
A01	Geological Survey of Alabama
	Georgia
E60	Georgia Department of Natural Resources
	Kentucky
I00	Kentucky Department for Human Resources
I01	Kentucky Department for Natural Resources and Environmental Protection
	Mississippi
L55	Mississippi State Board of Health
	North Carolina
Q00	North Carolina Department of Human Resources
Q01	North Carolina Department of Natural and Economic Resources
	Tennessee
U50	Tennessee Wildlife Resources Agency
U51	Tennessee Department of Public Health
U52	Cleveland Water System
U54	Bristol Water Plant
U55	University of Tennessee Experiment Station
U57	Water Resources Research Center, University of Tennessee

REGION 7

FEDERAL AGENCIES

CE	Corps of Engineers (Army)

EPA	Environmental Protection Agency
ERD	Energy Research and Development Administration
FS	Forest Service (Agriculture)
FWS	Fish and Wildlife Service (Interior)
GS	Geological Survey (Interior)
NWS	National Weather Service (Commerce)

NON-FEDERAL AGENCIES

Illinois

G00	Illinois Department of Public Health
G01	Metropolitan Sanitary District of Greater Chicago
G02	Illinois Department of Registration and Education
G03	Illinois Department of Public Works and Buildings

Indiana

G50	Indiana State Board of Health

Iowa

H00	Iowa State Hygenic Laboratory
H02	Des Moines Water Works
H03	Ottumwa Water Works
H05	Iowa Department of Preventive Medicine and Environmental Health
H06	Agricultural Engineering Department, Iowa State University
H07	Fort Dodge Department of Municipal Utilities
H09	Des Moines County Drainage District No. 7
H10	Green Bay Levee and Drainage District No. 2

Minnesota

L00	Hennepin County Highway Department
L02	Minnesota Department of Natural Resources
L03	Otter Tail Power Company
L04	Ramsey County Engineer's Department
L05	Northern State Power Company
L08	Blandin Paper Company
L09	Minnesota Power and Light Company
L10	Metropolitan Sewer Board
L11	Minnesota Pollution Control Agency
L12	Washington County Highway Department

Missouri

M00	Division of Health of Missouri
M02	University of Missouri at Rolla
M03	Metropolitan St. Louis Sewer District
M04	Little River Drainage District
M06	Missouri Clean Water Commission

Wisconsin

Y00	Wisconsin Department of Natural Resources
Y02	Dairyland Power Cooperative
Y04	Northern States Power Company

REGION 8

FEDERAL AGENCIES

CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
GS	Geological Survey (Interior)
MFS	National Marine Fisheries Service (Commerce)
NFE	Naval Facilities Engineering Command
NWS	National Weather Service (Commerce)
TVA	Tennessee Valley Authority

NON-FEDERAL AGENCIES

Arkansas

B50	Bureau of Environmental Engineering, Arkansas State Department of Health
B51	Arkansas Game and Fish Commission
B52	Arkansas Pollution Control and Ecology

Kentucky

I00	Kentucky Department for Human Resources
I01	Kentucky Department for Natural Resources and Environmental Protection

Louisiana

I51	Louisiana State Department of Health
I52	Houma Light and Water Plant
I53	Jefferson Water Works District No. 2
I54	Lafourche Water Works District No. 1
I55	East Jefferson Water Works District No. 1
I56	New Orleans Sewerage and Water Board
I58	Utilities Commission Water Treatment Plant, City of Monroe
I59	Louisiana Wildlife and Fisheries Commission, Division of Water Pollution Control

Mississippi

L50	City of Vicksburg Water Treatment Plant
L55	Mississippi State Board of Health

Missouri

M00	Division of Health of Missouri
M04	Little River Drainage District
M06	Missouri Clean Water Commission

Tennessee

U50	Tennessee Wildlife Resources Agency
U51	Tennessee Department of Public Health
U55	University of Tennessee Experiment Station

REGION 9

FEDERAL AGENCIES

CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
NWS	National Weather Service (Commerce)

CANADA

WQB	Environment Canada, Water Quality Branch
WSC	Environment Canada, Water Resources Branch

NON-FEDERAL AGENCIES

Minnesota

L02	Minnesota Department of Natural Resources
L03	Otter Tail Power Company
L07	Minnesota Ore Operations, USS Corp.
L09	Minnesota Power and Light Company
L11	Minnesota Pollution Control Agency

North Dakota

Q50	North Dakota Game and Fish Department
Q51	North Dakota State Department of Health
Q52	Minot City Water Treatment Plant
Q55	Grand Forks Water Treatment Plant

REGION 10

FEDERAL AGENCIES

BR	Bureau of Reclamation (Interior)
CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
FS	Forest Service (Agriculture)
FWS	Fish and Wildlife Service (Interior)
GS	Geological Survey (Interior)
NFE	Naval Facilities Engineering Command (Navy)
NWS	National Weather Service (Commerce)
SCS	Soil Conservation Service (Agriculture)

CANADA

WQB	Environment Canada, Water Quality Branch
WSC	Environment Canada, Water Resources Branch

NON-FEDERAL AGENCIES

	Colorado
C50	Board of Water Commissioners, City and County of Denver
C51	Division of Water Resources, Office of Colorado State Engineer
C53	Boulder City County Health Department
	Iowa
H00	Iowa State Hygenic Laboratory
H01	Director of Lakeside Laboratory, University of Iowa
H06	Agricultural Engineering Department, Iowa State University
H08	Council Bluffs Water Works
	Kansas
H50	Kansas State Department of Health
H51	Board of Public Utilities, Kansas City
H52	Kansas State Board of Agriculture
H53	Topeka Water Department
H54	Kansas Forestry, Fish, and Game Commission
	Minnesota
L02	Minnesota Department of Natural Resources
L11	Minnesota Pollution Control Agency

Missouri

M00	Division of Health of Missouri
M06	Missouri Clean Water Commission
M07	Union Electric Company, Bagnell Dam

Montana

M50	Montana Fish and Game Department
M51	Montana University Joint Water Resources Research Center
M52	Montana State Department of Health and Environmental Sciences
M53	Montana Department of Natural Resources and Conservation

Nebraska

N00	Nebraska Game and Parks Commission
N01	State of Nebraska Department of Environmental Control
N02	Metropolitan Utilities District, City of Omaha
N03	Soil and Water Testing Laboratory, University of Nebraska

North Dakota

Q50	North Dakota Game and Fish Department
Q51	North Dakota State Department of Health
Q52	Minot City Water Treatment Plant
Q53	City of Bismarck Water Department
Q54	City of Dickinson Water Treatment

South Dakota

U00	Water Resources Research Institute, South Dakota State University
U01	East Dakota Conservancy Sub-District

Wyoming

Y50	City of Casper Board of Public Utilities
Y51	Sheridan Water Department
Y52	Wyoming State Engineer
Y53	Water Resources Research Institute, University of Wyoming

REGION 11

FEDERAL AGENCIES

BR	Bureau of Reclamation (Interior)
CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency

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FS	Forest Service (Agriculture)
FWS	Fish and Wildlife Service (Interior)
GS	Geological Survey (Interior)
NFE	Naval Facilities Engineering Command
NWS	National Weather Service (Commerce)

NON-FEDERAL AGENCIES

Arkansas

B50	Arkansas State Department of Health
B51	Arkansas Game and Fish Commission
B52	Arkansas Pollution Control and Ecology

Colorado

C51	Division of Water Resources, Office of State Engineer
C52	City of Colorado Springs, Water Division
C54	Pueblo Board of Water Works

Kansas

H50	Kansas State Department of Health
H52	Kansas State Board of Agriculture
H54	Kansas Forestry, Fish and Game Commission

Louisiana

I51	Louisiana State Department of Health
I57	Bossier City Water Plant
I59	Louisiana Wildlife and Fisheries Commission
I60	City of Shreveport Department of Water Utilities

Missouri

M00	Division of Health of Missouri
M06	Missouri Clean Water Commission

Oklahoma

R50	Oklahoma State Department of Health

Texas

V00	Texas Water Development Board

REGION 12

FEDERAL AGENCIES

CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
GS	Geological Survey (Interior)

IBW	International Boundary and Water Commission
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)

NON-FEDERAL AGENCIES

Louisiana

I59	Louisiana Wildlife and Fisheries Commission

Texas

V00	Texas Water Development Board

REGION 13

FEDERAL AGENCIES

BR	Bureau of Reclamation (Interior)
CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
IBW	International Boundary and Water Commission
NWS	National Weather Service (Commerce)

NON-FEDERAL AGENCIES

Colorado

C51	Division of Water Resources, Office of Colorado State Engineer

New Mexico

P00	New Mexico State Engineer's Office

REGION 14

FEDERAL AGENCIES

BR	Bureau of Reclamation (Interior)
EPA	Environmental Protection Agency
FS	Forest Service (Agriculture)
FWS	Fish and Wildlife Service (Interior)

GS	Geological Survey (Interior)
NWS	National Weather Service (Commerce)

NON-FEDERAL AGENCIES

Colorado

C50	Board of Water Commissioners, City and County of Denver
C51	Division of Water Resources, Office of Colorado State Engineer
C52	City of Colorado Springs, Water Division

Utah

V50	Utah State Health Department
V52	Utah Department of Natural Resources

Wyoming

Y52	Wyoming State Engineer

REGION 15

FEDERAL AGENCIES

BLM	Bureau of Land Management (Interior)
BR	Bureau of Reclamation (Interior)
CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
IBW	International Boundary and Water Commission
NWS	National Weather Service (Commerce)
SCS	Soil Conservation Service (Agriculture)

NON-FEDERAL AGENCIES

Arizona

B00	Salt River Project
B01	Water Resources Research Center, University of Arizona
B02	Roosevelt Irrigation District
B03	Arizona Game and Fish Department
B04	Maricopa County Municipal Water Conservation
B05	Gila Water Commissioner

California

C00	California Department of Water Resources

Nevada

N50	Nevada State Health Division

Utah

V50	Utah State Health Department

REGION 16

FEDERAL AGENCIES

BLM	Bureau of Land Management (Interior)
BR	Bureau of Reclamation (Interior)
CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
ERD	Energy Research and Development Administration
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
NFE	Naval Facilities Engineering Command (Navy)
NWS	National Weather Service (Commerce)
SCS	Soil Conservation Service (Agriculture)

NON-FEDERAL AGENCIES

California

C00	California Department of Water Resources

Idaho

F50	Idaho State Fish Hatchery
F52	Idaho Department of Environmental and Community Services

Nevada

N50	Nevada State Health Division
N51	Walker River Irrigation District

Utah

V50	Utah State Health Department
V51	Metropolitan Water District of Salt Lake City
V53	Salt Lake County Water Conservancy District
V54	Salt Lake City Water Supply and Waterworks
V55	Ogden Bay Waterfowl Management Area
V56	Clear Lake Waterfowl Management Area
V58	Utah Geological and Mineralogical Survey
V59	Ogden River Water Users
V60	Weber Distribution System

REGION 17

FEDERAL AGENCIES

BPA	Bonneville Power Administration (Interior)
BR	Bureau of Reclamation (Interior)
CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
ERD	Energy Research and Development Administration
FS	Forest Service (Agriculture)
FWS	Fish and Wildlife Service (Interior)
GS	Geological Survey (Interior)
MC	Marine Corps (Navy)
MFS	National Marine Fisheries Service (Navy)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)
SCS	Soil Conservation Service (Agriculture)

CANADA

WQB	Environment Canada, Water Quality Branch
WSC	Environment Canada, Water Resources Branch

NON-FEDERAL AGENCIES

Idaho

F51	Water Resources Research Institute, University of Idaho
F52	Idaho Department of Environmental and Community Services

Montana

M50	Montana Fish and Game Department
M53	Montana Department of Natural Resources and Conservation

Nevada

N50	Nevada State Health Division

Oregon

S00	Department of Forest Engineering, Oregon State University
S01	Oregon Wildlife Commission
S02	Douglas County Water Resource Survey
S03	Oregon State Engineer
S04	Fish Commission of Oregon
S13	Portland General Electric

Washington

X00	State of Washington, Department of Ecology, Water Resources Division
X01	Public Utility District No. 1, Skagit County
X02	Chelan County PUD No. 1
X03	College of Fisheries, University of Washington
X04	College of Engineering Research, Washington State University
X05	Department of Zoology, University of Washington
X06	City of Bremerton Water Department
X07	City of Everett Department of Water
X08	Seattle Water Department
X09	City of Tacoma, Department of Public Utilities
X12	Municipality of Metropolitan Seattle
X16	King County, Washington, Department of Public Works
X19	The Washington Water Power Company
X20	Douglas County Public Utility District
X21	Public Utility District of Grant County
X24	Puget Sound Power and Light Company
X25	City of Seattle

REGION 18

FEDERAL AGENCIES

BLM	Bureau of Land Management (Interior)
BR	Bureau of Reclamation (Interior)
CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
IBW	International Boundary and Water Commission
MC	Marine Corps (Navy)
MFS	National Marine Fisheries Service (Commerce)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)
SCS	Soil Conservation Service (Agriculture)

NON-FEDERAL AGENCIES

California

C00	California Department of Water Resources
C01	Los Angeles County Flood Control District
C03	Alameda County Water District
C04	County of Sacramento, Water Resources Division
C05	Whitewater Mutual Water Company

C06	California Water Quality Control Board
C09	Ventura County Flood Control District
C10	San Diego Department of Sanitation and Flood Control
C11	Orange County Flood Control District
C12	Merced Irrigation District
C13	Turlock Irrigation District
C14	Tridam Irrigation District
C15	Pacific Gas and Electric
C16	Oroville-Wyandotte Irrigation District
C17	Mosquito Irrigation District
C18	Contracting Entities
C19	East Bay Municipal Utility District
C20	Modesto Irrigation District
C21	El Nido Irrigation District
C22	Madera Irrigation District
C23	Hetch Hetchy Water Supply, City and County of San Francisco
C24	Southern California Edison Company
C25	Pacific Power and Light
C26	Kings River Water Association
C27	Fresno Irrigation District
C28	Kaweah and St. Johns Water Association
C29	Tulare Irrigation District
C30	Delano-Earlimart Irrigation District
C31	Kern County Land Company
C32	Buena Vista Water Storage District
C33	Terra Bella Irrigation District
C34	Sausalito Irrigation District
C35	Monterey County Flood Control and Water Conservation District
C36	San Luis Obispo County Flood Control and Water Conservation District
C37	Montecito County Water District
C38	Santa Barbara County Flood Control and Water Conservation District
C39	Metropolitan Water District of Southern California
C40	Marin Municipal Water District
C41	Marin, North, County Water District
C42	Sonoma County Flood Control and Water Conservation District
C43	Alameda County Flood Control and Water Conservation District
C44	Santa Clara Valley Water District
C45	Tule Irrigation District
C46	Montague Water Conservation District
C47	City of Los Angeles, Dept. of Water and Power
C48	Palm Springs Water Company
C49	Escondido Mutual Water Company

Z00	San Bernardino County Flood Control District
Z01	San Antonio Water Company
Z02	Temescal Water Company
Z03	Riverside County Flood Control and Water Conservation District
Z04	Ventura River Municipal Water District
Z05	Ventura County Water Resources Division
Z06	United Water Conservation District
Z07	Kings River Water Conservation Board
Z08	La Canada Irrigation District
Z09	San Gabriel Electric Company

Nevada

N50	Nevada State Health Division
N54	Nevada Irrigation District

Oregon

S01	Oregon Wildlife Commission
S03	Oregon State Engineer

REGION 19

FEDERAL AGENCIES

EPA	Environmental Protection Agency
FS	Forest Service (Agriculture)
GS	Geological Survey (Interior)
MC	Marine Corps (Navy)
MFS	National Marine Fisheries Service (Commerce)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)
SCS	Soil Conservation Service (Agriculture)

CANADA

WSC	Environment Canada, Water Resources Branch

NON-FEDERAL AGENCIES

Alaska

A50	Chugach Electric Association
A51	Alaska Department of Highways
A55	Alaska Department of Environmental Conservation

	Washington
X03	College of Fisheries, University of Washington

REGION 20

FEDERAL AGENCIES

CE	Corps of Engineers (Army)
EPA	Environmental Protection Agency
GS	Geological Survey (Interior)
MC	Marine Corps (Navy)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Interior)

NON-FEDERAL AGENCIES

	Hawaii (and other Pacific Islands)
F00	Board of Water Supply, City and County of Honolulu
F01	Department of Water, County of Kauai
F02	Board of Water Supply, County of Maui
F03	Board of Water Supply, County of Hawaii
F04	Department of Hawaiian Home Lands, State of Hawaii
F05	Department of Land and Natural Resources, State of Hawaii, Division of Fish and Game
F06	Department of Land and Natural Resources, State of Hawaii, Division of Water and Land Development
F07	Public Utility Agency Water Division, Government of Guam
F08	Ryukyu Industrial Research Institute, Government of Ryukyu Islands
F09	Ryukyu Meteorological Agency, Government of Ryukyu Islands

REGION 21

FEDERAL AGENCIES

GS	Geological Survey (Interior)
NFE	Naval Facilities Engineering Command (Navy)
NOS	National Ocean Survey (Commerce)
NWS	National Weather Service (Commerce)

NON-FEDERAL AGENCIES

Puerto Rico

T01	Puerto Rico Water Resources Authority

APPENDIX B

MONITOR SITES CONSIDERED FOR ANALYSIS

This appendix contains a listing of the 104 monitor sites that were considered for analysis in this study. All the sites listed were considered to be sufficiently close to some populated area to warrant analysis. Further investigation sometimes revealed that data were not available or some other factor was present and prevented analysis. Those sites that could not be used and the reasons why are identified in Table B-1.

TABLE B-1. LIST OF ALL SITES CONSIDERED FOR DAILY OR HOURLY ANALYSIS

State	Station name	Agency[*]	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
Alabama	Coosa R. at Verbena	GS	324756	862602	Stream	1974	Yes	Montgomery	–	4
	Coosa R. at Gadsen	EPA	340057	855843	Stream	1971	Yes	Gadsen	–	4
Colorado	S. Platte R., 60 ave.	EPA	394826	1045730	Stream	1968	Yes	Denver	<10	1
	S. Platte R., 88 ave.	EPA	395115	1045615	Stream	1968	Yes	Denver	<10	1
	Burlington Ditch at York St.	EPA	394802	1045730	Canal	1967	Yes	Denver	<10	1
	Sand Cr. at Burlington Ditch	EPA	394837	1045659	Stream	1967	Yes	Denver	<10	1
Georgia	Chattahoochee R. at Atlanta	EPA	335132	842716	Stream	1960	Yes	Atlanta	10	1
	Peachtree Cr. near Atlanta[†]	GS	335133	842716	Stream	–	No	Atlanta	10	1
	Ocmulgee R. near Warner-Robins[†]	GS	324017	833611	Stream	1970	No	Macon	20	4
Illinois	Calumet R. STW[†]	G01	413946	873940	Canal	1969	No	Chicago	20	2
	Chicago R. Bridge[†]	G01	415333	873832	Stream	1969	Yes	Chicago	5	1
	Chicago Sanitation and Ship Canal at Lockport[†]	G01	413408	880441	Canal	1969	Yes	Chicago	35	2
Louisiana	Bayou Teche at Olivier	GS	295718	914254	Stream	1972	Yes	–	–	–
	Houma Nav. Canal near Dulac[†]	GS	292306	904347	Stream	1973	No	–	–	–

[*] The agency codes, taken from OWDC, identify the agency that was in charge of the data; specifically, GS = Geological Survey, EPA = Environmental Protection Agency, G01 = Metropolitan Sanitation District of Greater Chicago, R02 = ORSANCO, WDNR = Wisconsin Department of Natural Resources.

[†] Site was later dropped.

(continued)

TABLE B-1 (continued).

State	Station name	Agency	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
Louisiana (continued)	Ouachita R. at Monroe	GS	323019	920732	Stream	1954	Yes	Shreveport	90	4
Massachusetts	Blackstone R. at Millville	GS	420116	713404	Stream	1969	Yes	–	–	4
	Connecticut R. at W. Springfield	GS	420546	723543	Stream	1972	Yes	Hartford	25	2
	Connecticut R. at Agawam†	GS	420257	723635	Stream	1968	Yes	Hartford	25	2
	Hoosic R. below Williamston	GS	424428	731247	Stream	1968	Yes	–	–	4
	Merrimack R. at W. Newbury	GS	424838	710002	Stream	1969	Yes	–	–	4
	Merrimac R. above Concord R. at Lowell†	GS	423857	711950	Stream	1967	No	Boston	25	4
	N. Nashua R. near Leominster	GS	423006	714323	Stream	1968	Yes	–	–	4
	Quinebaug R. near Dudley	GS	420140	715722	Stream	1968	Yes	–	–	4
	Westfield R. at Westfield	GS	420559	723828	Stream	1972	Yes	Hartford	25	2
	Chicopee R. at Chicopee Falls	GS	420937	723452	Stream	1973	Yes	Hartford	30	4
Mississippi	Yellow Cr. near Doskie	GS	345402	881735	Stream	1973	Yes	–	–	4
Maine	Vermillion R. near Empire City	GS	444000	930317	Stream	1974	Yes	–	–	4

(continued)

TABLE B-1 (continued).

State	Station name	Agency	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
Missouri	Center Cr. near Carterville	GS	370826	942257	Stream	1962	Yes	Springfield	70	4
	James R. near Boaz	GS	370025	932150	Stream	1972	Yes	Springfield	25	4
	Wilsons Cr. near Battlefield	GS	370702	932414	Stream	1972	Yes	Springfield	20	2
	Wilsons Cr. near Springfield	GS	370706	932414	Stream	1967	Yes	Springfield	20	2
New Jersey	Delaware R. at Trenton	GS	401318	744642	Stream	1923	Yes	Trenton	10	1
	Manasquan R. at Squankum	GS	400947	740921	Stream	1970	Yes	–	–	4
	Pompton R. at Two Bridges	GS	405352	741622	Stream	1969	Yes	Trenton	10	1
	Passaic R. at Little Falls†	GS	405305	741335	Stream	1963	Yes	Newark	15	1
	Raritan R. at S. Bound Brook	GS	403305	743254	Stream	–	Yes	–	–	4
North Carolina	Cape Fear R. at Channel Marker 50	EPA	341533	775624	Stream	1974	Yes	Wilmington	<10	1
	Muddy Cr. 500' below effluent	EPA	360312	794424	Stream	1974	Yes	Greensboro	–	2
	N. Fork Muddy Cr.	EPA	360220	801810	Stream	1974	Yes	Winston-Salem	–	2
	Muddy Cr. at S.R. 1485	EPA	355690	802100	Stream	1974	Yes	Winston-Salem	–	2
	Muddy Cr. at S.R. 2991	EPA	360030	802000	Stream	1974	Yes	Winston-Salem	–	2

(continued)

TABLE B-1 (continued).

State	Station name	Agency	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
	Roanoke, R. 1 mi. upstream of Welch Cr.	EPA	355200	764700	Stream	1974	Yes	–	–	4
	Neuse R. at U.S. 70	EPA	353041	782100	Stream	1975	Yes	–	–	4
	Neuse R. at U.S. 42	EPA	353815	782347	Stream	1975	Yes	–	–	4
	Neuse R. at U.S. 98	EPA	355840	783800	Stream	1975	Yes	–	–	4
	Neuse R. at U.S. 50	EPA	360052	789130	Stream	1975	Yes	–	–	4
Ohio	Ashtabula R. at Ashtabula	GS	415400	804744	Stream	1968	Yes	Cleveland	60	2
	Black R. at Elyria	GS	412442	820545	Stream	1966	Yes	Cleveland	20	4
	Black Fork at Loudonville	GS	403809	821422	Stream	1968	Yes	Mansfield	20	4
	Blanchard R. near Findlay	GS	410321	834117	Stream	1965	Yes	Toledo	50	4
	Cuyahoga R. at Independence	GS	412343	813748	Stream	1948	Yes	Cleveland	10	1
	Cuyahoga R. at Old Portage	GS	410808	813250	Stream	1965	Yes	Cleveland	25	1
	Cuyahoga R. at Superior St. Bridge[†]	GS	412939	814212	Stream	1950	Yes	Cleveland	10	1
	Cuyahoga R. at W. 3rd St. Bridge	GS	412917	814107	Stream	1966	Yes	Cleveland	10	1
	Grand R. near Painsville	GS	414409	811559	Stream	1950	Yes	Cleveland	25	4
	Hocking R. below Athens	GS	391939	820018	Stream	1966	Yes	Parkersburg, WV.	30	4
	Huron R. below Milan	GS	412006	823438	Stream	1970	Yes	–	–	3

(continued)

TABLE B-1 (continued).

State	Station name	Agency	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
Ohio (continued)	Little Miami R. at Miamiville	GS	391238	841733	Stream	1970	Yes	Cincinnati	15	3
	Little Miami R. near Spring Valley	GS	393500	840149	Stream	1968	Yes	Dayton	15	3
	Mad R. near Dayton	GS	394750	840519	Stream	1961	Yes	Dayton	10	3
	Mahoning R. at OH.-PA. State Line below Lowellville	GS	410153	803110	Stream	1967	Yes	Youngstown	10	1
	Maumee R. at Defiance	GS	411643	842307	Stream	1966	Yes	Toledo	50	4
	Maumee R. at Mouth at Toledo	GS	414136	832820	Stream	1967	Yes	Toledo	5	1
	Maumee R. at Waterville	GS	413000	834246	Stream	1950	Yes	Toledo	25	3
	Muskingham R. at McConnelsville	GS	393842	815100	Stream	1950	Yes	Parkersburg, WV	35	4
	Ohio R. at West End (Cincinnati)†	R02	None Published		Stream	1961	No	Cincinnati	10	1
	Ohio R. at Andersons Ferry†	R02	None Published		Stream	1961	No	Cincinnati	10	1
	Portage R. at Woodville	GS	412658	832129	Stream	1971	Yes	–	–	3
	Sandusky R. near Freemont	GS	412212	830610	Stream	1970	Yes	–	–	3
	Sandusky R. near Upper Sandusky	GS	405102	831523	Stream	1965	Yes	Mansfield	40	4
	Scioto R. at Chillicothe	GS	392029	825816	Stream	1950	Yes	Columbus	40	1
	Scioto R. below Shadeville	GS	394737	830040	Stream	1965	Yes	Columbus	5	1

(continued)

TABLE B-1 (continued).

State	Station name	Agency	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
Ohio (continued)	Tuscarawas R. at Navarre	GS	404336	813147	Stream	1970	Yes	–	–	3
Oregon	S. Umpqua R. near Brockway	GS	431320	1232445	Stream	1970	Yes	Eugene	60	4
	Willamette R. at Portland†	EPA	453349	1224317	Stream	1962	Yes	Portland	5	1
	Willamette R. at Oregon City†	EPA	452154	1223603	Stream	1968	Yes	Portland	20	4
	Willamette R. above Oregon City†	EPA	452030	1223733	Stream	1968	Yes	Portland	20	4
Pennsylvania	Allegheny R. at Oakmont†	R02	None Published		Stream	1962	Yes	Pittsburgh	15	3
	Beaver R. at Beaver Falls†	R02	4048	8019	Stream	1961	No	Pittsburgh	40	4
	Delaware R. at Bristol	GS	400455	745158	Estuary	1949	Yes	Trenton	10	3
	Delaware R. at Chester	GS	395012	752200	Esutary	1961	Yes	Philadelphia	20	2
	Delaware R. at Easton	GS	404243	751148	Stream	1947	Yes	Allentown	15	3
	Delaware R. at Torresdale Intake	GS	400157	745946	Stream	1949	Yes	Philadelphia	10	2
	Kiskiminetas R. at Vandergrift†	R02	403620	793315	Stream	–	No	Pittsburgh	30	4
	Monongahela R. at S. Pittsburgh†	R02	402436	795715	Stream	–	Yes	Pittsburgh	10	1
	Lehigh R. at Easton	GS	404112	751232	Stream	1961	Yes	Allentown	15	3

(continued)

TABLE B-1 (continued).

State	Station name	Agency	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
Pennsylvania (Continued)	Schuylkill R. at Philadelphia	GS	395800	751120	Stream	1945	Yes	Philadelphia	10	1
	W. Br. Brandywine Cr. at Modena	GS	395742	754806	Stream	1974	Yes	—	—	4
Tennessee	W. Fork Stones R. at Manson Park	GS	355125	862443	Stream	1973	Yes	Nashville	25	4
Texas	Trinity R. below Dallas	GS	324227	964408	Stream	1967	Yes	Dallas	20	1
Virginia	N. Fork Holston R. near Gate City†	EPA	363631	823405	Stream	1969	Yes	Bristol, TN.	25	4
Washington	Green-Duwamish R. Station 307	EPA	None Published		Stream	1969	Yes	—	—	—
West Virginia	Ohio R. at Huntington†	R02	3825	8225	Stream	1961	Yes	Huntington	5	1
Wisconsin	Fox R. at Menasha	WDNR	441151	882653	Stream	1971	Yes	Green Bay	30	4
	Fox R. at Appleton	WDNR	441517	882443	Stream	1971	Yes	Green Bay	25	4
	Fox R. at Rapide Croche	WDNR			Stream	1971	Yes	—	—	4
	Fox R. at DePere	WDNR	442653	880402	Stream	1971	Yes	Green Bay	5	3
	Fox R. at Green Bay	WDNR	443129	880026	Stream	1971	Yes	Green Bay	5	1
	Wisconsin R. at Wasau	WDNR	445725	893808	Stream	1971	Yes	Green Bay	90	4

(continued)

TABLE B-1 (continued).

State	Station name	Agency	Lat.	Long.	Site	Established	Water discharge available?	Primary rain gage	Distance to rain gage (mi)	Applicability to study code
Wisconsin (continued)	Wisconsin at Moisinee	WDNR	–	–	Stream	1971	Yes	Green Bay	–	–
	Wisconsin at Dubay Dam	WDNR	442450	895121	Stream	1971	Yes	Green Bay	90	4
	Wisconsin at Biron	WDNR	–	–	Stream	1971	Yes	Green Bay	–	–
	Wisconsin at Port Edwards	WDNR	442552	894647	Stream	1971	Yes	Green Bay	90	4
	Wisconsin at Petenwell	WDNR	–	–	Stream	1971	Yes	Green Bay	–	–

APPENDIX C

RESULTS OF DAILY CORRELATION ANALYSIS

This appendix contains the results of all the daily correlation analyses for both flow and rainfall. Table C-1 contains the results of flow correlation analysis at USGS monitor sites. Table C-2 contains the results of flow correlation analyses for STORET data base monitors. Table C-3 contains the results of the flow correlation analyses for the WDNR monitor sites. Table C-4 contains the results of daily rainfall correlation analysis at the USGS monitor sites.

In the following tables the stations are grouped by state. The states are in alphabetical order and the stations in a group are alphabetized. Three types of statistics are included in each table. These are the probability of a worse than average dissolved oxygen deficit, the strength of the deficit, and the average percent saturation which occurs when the dissolved oxygen deficit is worse than average. The three types of statistics answer the following six questions about a given monitor site:

- What is the probability at this station that a worse-than-average (seven-day moving) DO deficit will occur on a wetter-than-average (seven-day moving) day?
- What is the probability at this station that a worse-than-average (seven-day moving) DO deficit will occur on a dryer-than-average (seven-day moving) day?
- If the DO deficit on a particular wetter-than-average day is worse than average, how much worse is it?
- If the DO deficit on a particular dryer-than-average day is worse than average, how much worse it it?
- On wetter-than-average days when the DO deficit is worse than average, what percentage of saturation is present?
- On dryer-than-average days when the DO deficit is worse than average, what percentage of saturation is present?

TABLE C-1. USGS MONITOR SITE SUMMARY OF DAILY FLOW CORRELATION ANALYSIS RESULTS

Monitor site*	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
ALABAMA							
Coosa R. near Verbena	74	— ABORTED	—	—	—	—	—
(at Jordan Dam near	75	.44	.60	1.16	1.46	.62	.72
Wetumbwa)							
LOUISIANA							
Bayou Teche at Olivier	72-	— ABORTED	—	—	—	—	—
(at Keystone Lock near	74						
St. Martinsville)	75	.52	.53	1.15	1.18	.24	.31
Houma Nav. Canal at	74-	— ABORTED	—	—	—	—	—
Dulac	75						
Quachita R. at Monroe	69	.45	.60	1.39	1.35	.29	.47
	70	.50	.53	1.19	1.21	.42	.33
	71	.51	.46	1.28	1.33	.35	.38
	72	.38	.46	1.28	1.36	.33	.43
MASSACHUSETTS							
Blackstone R. at Millville	69	— ABORTED	—	—	—	—	—
	70	.43	.65	1.09	1.11	.45	.49
	71	.48	.65	1.06	1.11	.44	.45
	72	.48	.63	1.15	1.09	.62	.55

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*Stations are grouped by state, states are in alphabetical order, stations are alphabetized within group; ABORTED indicates that less than 180 days of data were available that year.

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
MASSACHUSETTS (continued)							
Connecticut R. at W.	72	– ABORTED	–	–	–	–	–
Springfield (Thompsonville)	73	.46	.60	1.76	2.86	.72	.80
	74	.43	.60	1.27	1.25	.81	.79
	75	.41	.61	1.21	1.25	.81	.82
Hoosic R. below	73	– ABORTED	–	–	–	–	–
Williamstown	74	.46	.58	1.37	1.26	.64	.60
	75	– ABORTED	–	–	–	–	–
Merrimack R. at W.	72	.46	.57	1.63	1.54	.74	.74
Newbury	73	– ABORTED	–	–	–	–	–
	74	.44	.65	1.52	1.49	.55	.67
	75	.46	.52	1.50	2.48	.63	.72
	76	.47	.45	1.09	1.13	.63	.61
North Nashau R. near	68	ABORTED	–	–	–	–	–
Lancaster (Leominster)	69	.55	.58	1.14	1.13	.48	.53
	70	.63	.50	1.17	1.17	.53	.62
	71	.47	.52	1.14	1.12	.48	.57
	72	.32	.69	1.20	1.13	.66	.59
Quinebaug R. near Dudley	69	.38	.61	1.38	1.48	.83	.74
(at Quinebaug CN.)	70	.33	.52	2.14	1.79	.88	.83
	71	.47	.67	1.68	1.50	.74	.67
	72	.39	.66	1.28	1.24	.70	.71
Westfield R. at Westfield	72	– ABORTED	–	–	–	–	–
	73	.46	.51	1.42	2.46	.76	.75
	74	.52	.47	1.30	1.26	.79	.80

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
MASSACHUSETTS (continued)							
Westfield R. at Westfield	75	.62	.48	1.69	2.65	.78	.88
	76	.30	.48	1.68	1.79	.89	.82
MISSISSIPPI							
Yellow Cr. near Doskie	73	– ABORTED	–	–	–	–	–
	74	.58	.50	2.16	2.80	.74	.76
	75	– ABORTED	–	–	–	–	–
MAINE							
Vermillion R. near Empire	74	– ABORTED	–	–	–	–	–
	75	– ABORTED	–	–	–	–	–
MISSOURI							
Center Cr. near Carterville	72	.53	.52	1.68	1.71	.59	.57
	73	– ABORTED	–	–	–	–	–
	74	.49	.56	1.12	1.11	.58	.61
	75	.43	.58	1.10	1.16	.46	.56
	76	– ABORTED	–	–	–	–	–
James R. near Boaz	72	– ABORTED	–	–	–	–	–
	73	.44	.58	1.14	1.13	.53	.59
	74	.40	.64	1.11	1.14	.42	.50
	75	.43	.62	1.11	1.11	.32	.48
	76	.44	.57	1.09	1.11	.18	.31
Wilsons Cr. near Battlefield	73	.36	.63	1.06	1.10	.09	.13
	74	.51	.61	1.06	1.10	.06	.10

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19–)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
MISSOURI (CONTINUED)							
Wilsons Cr. near Battlefield (continued)	75	.53	.57	1.10	1.09	.10	.16
	76	.57	.54	1.04	1.05	.02	.04
Wilsons Cr. near Springfield	72	– ABORTED	–	–	–	–	–
	73	.70	.42	1.27	1.20	.60	.64
	74	.54	.48	1.30	1.18	.58	.64
	75	.81	.39	1.27	1.16	.56	.69
	76	.77	.44	1.28	1.14	.58	.65
NEW JERSEY							
Delaware R. at Trenton	72	.58	.49	2.12	4.60	.85	.87
	73	.64	.45	1.83	6.66	.85	.93
	74	.44	.47	2.75	2.74	.89	.91
	75	.61	.40	2.79	3.73	.91	.96
	76	.51	.51	4.71	3.66	.91	.97
Manasquan R. at Squankum (This station later abandoned for lack of urban area. It is near a swamp.)	70	.52	.48	1.20	1.16	.52	.56
	71	.61	.58	1.12	1.13	.51	.55
	72	.66	.52	1.22	1.11	.50	.56
	73	.55	.44	1.16	1.13	.68	.71
	74	.48	.52	1.26	1.22	.67	.70
Passaic R. at Two Bridges	72	.48	.69	1.07	1.09	.52	.42
	73	.34	.66	1.12	1.21	.48	.50
	74	– ABORTED	–	–	–	–	–
Raritan R. near South Bound Brook (below Callo Dam at Boundbrook)	74	– ABORTED	–	–	–	–	–
	75	.60	.37	1.60	1.65	.72	.80

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO							
Ashtabula R. at Ashtabula	72	.44	.54	1.29	1.35	.72	.67
	73	.52	.47	1.40	2.02	.76	.78
	74	.42	.57	1.50	1.32	.76	.72
	75	.63	.49	1.23	1.21	.64	.72
	76	.58	.50	1.25	1.21	.68	.69
Black R. at Elyria	70	— ABORTED	—	—	—	—	—
	71	— ABORTED	—	—	—	—	—
	72	— ABORTED	—	—	—	—	—
	73	.54	.52	1.81	1.47	.57	.63
	74	.49	.53	1.43	1.61	.57	.54
Black Fork at Loudonville	72	.57	.45	2.59	1.27	.60	.65
	73	.48	.51	?	1.49	.71	.73
	74	.52	.46	1.24	1.12	.67	.68
	75	.47	.50	1.21	1.12	.67	.74
	76	.56	.45	1.22	1.12	.67	.72
Blanchard R. near Findlay	72	.55	.39	2.96	1.67	.61	.69
	73	.53	.55	1.19	1.26	.63	.60
	74	.47	.59	1.14	1.11	.42	.44
	75	.49	.52	1.18	1.16	.47	.55
	76	.41	.60	1.23	1.19	.50	.61
Cuyahoga R. at Independence	72	.39	.58	1.23	1.16	.69	.62
	73	.54	.48	1.24	1.24	.70	.72
	74	.52	.56	1.15	1.15	.62	.65
	75	.42	.53	1.22	1.21	.69	.74
	76	.56	.47	1.24	1.14	.71	.75

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO (continued)							
Cuyahoga R. at Old Portage	72	.45	.51	2.27	1.18	.63	.67
	73	.37	.63	1.47	3.33	.72	.76
	74	.39	.58	1.24	1.35	.75	.75
	75	.47	.49	1.36	1.28	.58	.74
	76	.41	.61	1.25	1.22	.63	.74
Cuyahoga R. at W. 3rd St. Bridge	72	.47	.54	1.14	1.21	.41	.35
	73	.44	.54	1.10	1.11	.45	.37
	74	.43	.59	1.09	1.09	.38	.37
	75	.41	.51	1.13	1.12	.43	.41
	76	.45	.52	1.17	1.13	.38	.39
Grand R. near Painesville	75	.45	.67	1.16	1.18	.72	.68
	76	.34	.63	1.26	1.56	.63	.67
Hocking R. below Athens	72	.46	.55	2.02	1.33	.65	.64
	73	.50	.46	1.74	1.60	.82	.82
	74	.42	.55	1.39	1.34	.84	.84
	75	.57	.60	1.33	1.31	.79	.82
	76	.67	.45	1.44	1.40	.84	.86
Huron R. below Milan	70	— ABORTED	—	—	—	—	—
	71	.49	.52	1.54	1.51	.70	.78
	72	.43	.37	3.33	3.14	.81	.83
	73	.41	.54	2.21	5.60	.87	.80
	74	.57	.45	1.49	1.50	.77	.79
	75	.50	.49	1.76	2.24	.67	.72

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19–)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO (continued)							
Little Miami R. at Miamiville (Milford)	71	.59	.47	1.51	2.07	.68	.71
	72	.57	.37	1.85	2.37	.84	.81
	73	.66	.40	1.61	2.01	.83	.85
	74	.67	.37	1.56	1.42	.84	.86
Little Miami R. near Spring Valley	72	.58	.42	1.17	1.15	.62	.64
	73	.49	.40	1.49	1.30	.68	.71
	74	.65	.43	1.33	1.18	.73	.74
	75	.67	.45	1.18	1.14	.72	.76
	76	.59	.39	1.23	1.13	.63	.67
Mad R. near Dayton	72	.63	.47	1.25	1.13	.71	.71
	73	.50	.45	1.31	1.19	.76	.79
	74	.49	.52	1.19	1.13	.73	.72
	75	.56	.48	1.23	1.19	.73	.75
	76	.50	.54	1.16	1.19	.65	.71
Mahoning R. at OH.-PA. State Line (Lowellville)	73	.50	.54	1.16	1.29	.53	.53
	74	.38	.58	1.15	1.13	.54	.52
	75	.48	.54	1.10	1.09	.51	.57
	76	.39	.56	1.22	1.14	.47	.54
Maumee R. at Defiance	72	.51	.42	1.94	1.44	.74	.77
	73	.66	.41	1.37	1.29	.72	.67
	74	.56	.44	2.38	3.22	.63	.71
	75	.60	.38	7.64	1.77	.77	.76
	76	.55	.42	4.92	11.23	.78	.83

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO (continued)							
Maume R. at Mouth at Toledo	69- 70	— ABORTED	—	—	—	—	—
	71	.53	.52	6.65	1.41	.38	.44
	72	.49	.52	1.34	1.65	.46	.59
Maumee R. at Waterville	69	.42	.61	11.76	3.25	.79	.70
	70	— ABORTED	—	—	—	—	—
	71	— ABORTED	—	—	—	—	—
	72	.58	.49	1.45	1.63	.55	.64
Muskingum R. at McConnelsville	73	— ABORTED	—	—	—	—	—
	74	.57	.43	1.56	1.62	.80	.77
	75	.54	.43	1.69	2.57	.85	.85
	76	.45	.44	1.87	3.50	.81	.81
Portage R. at Woodville	71 72	— ABORTED	—	—	—	—	—
	73	.60	.44	1.43	1.75	.56	.62
	74	.54	.46	1.32	2.25	.64	.63
	75	.68	.40	1.76	1.72	.77	.83
Sandusky R. near Fremont	70	.52	.64	1.33	1.28	.52	.53
	71	.52	.54	1.19	1.22	.44	.60
	72	.53	.47	5.14	2.48	.65	.67
	73	.45	.68	1.45	9.71	.68	.65
	74	.42	.53	1.65	2.61	.63	.60
	75	.47	.48	1.34	1.26	.59	.75

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO (continued)							
Sandusky R. near	72	.52	.47	2.03	4.47	.78	.80
Upper Sandusky	73	.60	.46	1.58	1.87	.83	.76
	74	.57	.49	–	1.81	.71	.70
	75	.54	.46	2.67	1.57	.69	.75
	76	.64	.46	1.34	1.27	.71	.74
Scioto R. at	72	.64	.48	1.21	1.15	.41	.51
Chillicothe	73	.52	.59	1.19	1.15	.59	.65
	74	.52	.50	1.19	1.11	.47	.52
	75	.54	.48	1.21	1.16	.43	.60
	76	.58	.40	2.19	1.23	.51	.61
Scioto R. below	72	.39	.60	1.23	1.25	.42	.54
Shadeville	73	.31	.67	1.16	1.20	.58	.58
	74	.40	.63	1.12	1.13	.48	.46
	75	.56	.60	1.16	1.12	.43	.48
	76	.49	.55	1.14	1.16	.51	.59
Tuscarawas R. at	70	– ABORTED	–	–	–	–	–
Navarre (Massillion)	71	.54	.55	1.09	1.08	.17	.28
	72	.50	.54	1.12	1.10	.29	.26
	73	.43	.61	1.12	1.11	.41	.41
	74	.40	.64	1.06	1.09	.40	.32
	75	.40	.56	1.08	1.11	.45	.39

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OREGON							
South Umpqua near Brockway	72	.57	.42	3.25	1.91	.84	.88
	73	.56	.47	1.79	12.68	.83	.87
	74	.33	.48	3.57	1.94	.96	.82
	75	.49	.49	2.98	1.69	.87	.81
	76	.63	.55	3.82	2.30	.82	.83
PENNSYLVANIA							
Delaware R. at Bristol	72	.51	.53	1.21	1.22	.72	.68
	73	.56	.45	1.95	1.67	.77	.79
	74	.50	.61	1.69	2.00	.69	.65
	75	.71	.43	1.33	1.24	.84	.84
	76	— ABORTED	—	—	—	—	—
Delaware R. at Chester	72	.49	.62	1.05	1.07	.31	.28
	73	.67	.65	1.13	1.61	.36	.42
	74	.52	.73	1.04	1.06	.31	.33
	75	.35	.77	1.07	1.07	.37	.42
	76	.57	.54	1.07	1.07	.36	.42
Delaware R. at Easton	72	— ABORTED	—	—	—	—	—
	73	— ABORTED	—	—	—	—	—
	74	— ABORTED	—	—	—	—	—
	75	.50	.60	1.53	2.62	.85	.86
	76	.44	.49	2.33	1.83	.86	.92

(continued)

TABLE C-1 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
PENNSYLVANIA	72	.46	.52	1.24	1.30	.72	.70
(continued)	73	.49	.53	1.63	1.30	.58	.58
Delaware R. at Torresdale	74	.50	.49	1.17	1.18	.54	.52
Intake, Philadelphia	75	.44	.55	1.25	1.37	.59	.67
	76	.41	.62	1.19	1.58	.67	.74
Lehigh R. at Easton	72	.53	.58	1.28	1.55	.71	.78
(Glendon)	73	.46	.55	1.71	1.48	.83	.82
	74	.39	.63	1.44	4.43	.77	.75
	75	.37	.60	1.50	1.30	.80	.77
	76	.50	.55	2.85	1.24	.79	.83
Schuylkill R. at	69	.43	.54	1.25	1.47	.66	.72
Philadelphia	70	.48	.55	1.42	2.26	.66	.68
	71	.39	.58	1.45	1.60	.68	.71
	72	.61	.55	1.24	1.53	.76	.79
West Br. Brandywine	71	– ABORTED	–	–	–	–	–
Cr. at Modena	72	.44	.49	1.58	2.41	.83	.83
	73	.58	.53	1.32	1.76	.84	.81
	74	.53	.49	1.40	1.46	.69	.62
TENNESSEE							
W.F. Stones R. at Manson	73	– ABORTED	–	–	–	–	–
Pk., at Murpheesboro	74	– ABORTED	–	–	–	–	–
	75	.52	.53	1.71	2.29	.85	.86
	76	– ABORTED	–	–	–	–	–
TEXAS							
Trinity R. below Dallas	77	.60	.52	1.13	1.14	.28	.26

TABLE C-2. STORET DATA BASE MONITOR SITES
SUMMARY OF DAILY FLOW CORRELATION ANALYSIS RESULTS

Monitor site*	Water Year (19–)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
ALABAMA							
Coosa R. at Gadson	71	.58	.51	1.82	1.56	.88	.83
Coosa R. Left Side	72	.49	.41	1.72	2.00	.86	.88
	73	.47	.51	1.63	1.70	.82	.85
	74	.46	.52	1.34	1.31	.77	.78
	75	.56	.40	1.27	1.34	.73	.74
	76	.41	.43	1.40	1.49	.78	.79
	77	– ABORTED	–	–	–	–	–
COLORADO							
S. Platte R. at Denver	67	– ABORTED	–	–	–	–	–
Sand C. Birlington	70	.53	.48	1.17	1.13	.64	.66
Ditch MDSDD # 1	71	.55	.45	1.25	1.21	.68	.70
	72	.52	.50	1.63	1.41	.77	.79
	73	.51	.47	1.51	1.40	.79	.76
	74	.47	.53	1.22	1.26	.70	.72
	75	.50	.42	1.52	1.30	.84	.81
	76	.50	.56	1.61	1.79	.78	.84
	77	.41	.40	1.93	1.85	.89	.84
S. Platte R. at Denver	69	– ABORTED	–	–	–	–	–
S. Platte R. at 88th Ave.	70	.46	.51	1.09	1.11	.57	.57
MDSDD # 1	71	.51	.47	1.19	1.16	.68	.68
	72	.57	.55	1.17	1.14	.68	.67
	73	.51	.52	1.20	1.14	.70	.69
	74	.35	.65	1.09	1.12	.69	.79
	75	.52	.54	1.15	1.18	.67	.68

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*Stations are grouped by state, states are in alphabetical order, stations are alphabetized within group; ABORTED indicates that less than 180 days of data were available that year.

(continued)

TABLE C-2 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
COLORADO (continued)	76	.51	.40	1.29	1.21	.63	.67
S. Platte, 88 Ave. (cont.)	77	.50	.52	1.26	1.24	.62	.61
S. Platte R. at Denver	67	.48	.46	1.17	1.21	.35	.44
Burlington Ditch at York	68	.51	.46	1.47	1.11	.65	.64
St. MDSDD #1	69	.48	.57	1.09	1.08	.56	.55
	70	.49	.44	1.14	1.13	.67	.69
	71	.60	.44	1.35	1.30	.72	.72
	72	.52	.55	1.28	1.20	.67	.66
	73	.53	.56	1.14	1.15	.66	.67
	74	.37	.60	1.09	1.10	.68	.63
	75	.40	.46	1.13	1.10	.66	.68
Flow-S. Platte at Denver	68	.56	.58	1.29	1.09	.60	.65
S. Platte #60 Ave.	69	–	ABORTED –	–	–	–	–
MDSDD #1	70	.49	.48	1.15	1.14	.65	.68
	71	.57	.47	1.30	1.28	.75	.74
	72	.51	.54	1.26	1.23	.72	.69
	73	.47	.53	1.17	1.20	.73	.73
	74	.38	.56	1.14	1.19	.74	.71
	75	.42	.52	1.28	1.14	.76	.77
	76	.66	.44	1.21	1.28	.61	.70
	77	.53	.51	1.31	1.28	.60	.60
GEORGIA							
Chattahoochee R. at Atlanta	67-68	– ABORTED	–	highly intermittent data	–	–	–

(continued)

TABLE C-2 (CONTINUED).

Monitor site	Water Year (19–)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
NORTH CAROLINA							
Cape Fear R. at Lock #1	74	— ABORTED	—	—	—	—	—
near Kelly, Cape Fear R. at Channel Marker #50	75	.52	.55	1.20	1.20	.44	.40
Muddy Cr. near Muddy Cr.	74	.69	.45	1.24	1.38	.73	.68
500 below efficient discharge	75	.64	.44	1.46	1.38	.71	.74
Muddy Cr. near Muddy Cr.	74	— ABORTED	—	—	—	—	—
Muddy Cr. at SR 1485	75	.49	.45	1.64	1.75	.75	.79
Muddy Cr. near Muddy Cr.	74	.50	.52	1.13	1.24	.75	.75
Muddy Cr. at SR 2991	75	.53	.54	1.20	1.14	.73	.64
Muddy Cr. near Muddy Cr.	74	— ABORTED	—	—	—	—	—
NFK, Muddy Cr.	75	.51	.36	2.01	1.86	.81	.86
Roanoke R. at Roanoke Rapid	74	.55	.74	1.27	1.26	.68	.68
Roanoke R. 1 mi. upstream of Welch Cr.	75	.49	.55	1.27	1.19	.75	.65
Neuse R. near Northside	75	— ABORTED	—	—	—	—	—
Neuse R. at U.S. Hwy. 42	76	— ABORTED	—	—	—	—	—
Neuse R. near Northside	75	— ABORTED	—	—	—	—	—
Neuse R. at U.S. Hwy. 50	76	— ABORTED	—	—	—	—	—
Neuse R. near Northside	75	— ABORTED	—	—	—	—	—
Neuse R. at U.S. Hwy. 70	76	— ABORTED	—	—	—	—	—
Neuse R. near Northside	75	— ABORTED	—	—	—	—	—
Neuse R. at U.S. Hwy. 98	76	— ABORTED	—	—	—	—	—

(continued)

TABLE C-2 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
WASHINGTON							
Green R. at Tuckwilla Green Duwamish R. Sta. 307	69- 73	– ABORTED	–	–	–	–	–

TABLE C-3. WDNR MONITOR SITES SUMMARY OF DAILY FLOW CORRELATION ANALYSIS RESULTS

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
Fox R. at Menasha	73	.57	.39	3.15	2.31	.84	.87
	74	.47	.50	2.12	2.68	.87	.88
	75	.50	.48	1.75	1.73	.85	.87
	76	.46	.62	1.29	1.50	.82	.80
	77	.58	.47	1.58	2.32	.83	.86
Fox R. at Appleton	73	.54	.56	1.34	1.42	.73	.69
	74	.48	.45	1.92	1.37	.80	.74
	75	.42	.50	1.34	1.33	.81	.74
	76	.43	.50	1.39	1.52	.77	.77
	77	.52	.57	1.55	1.25	.78	.78
Fox R. at Rapide Croche	73	.40	.60	1.69	1.65	.70	.61
	74	.41	.59	1.38	1.58	.71	.54
	75	.45	.59	1.28	2.74	.65	.60
	76	.46	.63	1.31	1.14	.62	.56
	77	.48	.59	1.29	1.20	.60	.60
Fox R. at Depere	73	.53	.54	1.80	1.45	.75	.81
	74	.39	.56	1.51	1.59	.82	.78
	75	.47	.54	2.51	1.67	.75	.73
	76	.47	.59	1.28	1.29	.76	.72
	77	.46	.52	1.39	1.48	.69	.71
Fox R. at Green Bay	73	.48	.58	1.26	1.59	.66	.56
	74	.41	.55	1.34	1.31	.74	.61

(continued)

TABLE C-3 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
Fox R. at Green Bay (continued)	75	.44	.59	1.29	1.40	.66	.56
	76	.44	.43	1.14	1.24	.72	.58
	77	.56	.49	1.17	1.16	.57	.60
Wisconsin R. at Wausau	73	.40	.58	1.12	1.13	.70	.76
	74	.56	.63	1.18	1.32	.71	.71
	75	.57	.55	1.14	1.14	.62	.59
	76	.45	.57	1.15	1.16	.54	.55
	77	.49	.54	1.19	1.10	.56	.60
Wisconsin R. at Mosinee	73	.40	.66	1.20	1.16	.51	.54
	74	.38	.57	1.06	1.14	.46	.44
	75	.47	.58	1.12	1.25	.40	.38
	76	.53	.62	1.06	1.12	.33	.36
	77	.44	.61	1.09	1.13	.40	.52
Wisconsin R. at Dubay Dam	72	.55	.59	1.10	1.13	.27	.36
	73	.52	.60	1.11	1.15	.52	.56
	74	.60	.52	1.08	1.11	.36	.44
	75	.58	.55	1.13	1.18	.47	.49
	76	.64	.50	1.08	1.13	.36	.44
Wisconsin R. at Biron	72	.48	.68	1.13	1.47	.46	.56
	73	.42	.59	1.24	1.38	.72	.79
	74	.64	.46	1.48	1.13	.60	.62
	75	.49	.52	1.18	2.04	.61	.71
	76	.50	.54	1.14	1.20	.50	.64

(continued)

TABLE C-3 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
Wisconsin R. at Port Edwards	73	.42	.59	1.24	1.38	.72	.79
	74	.54	.59	1.14	1.42	.56	.61
	75	.44	.70	1.11	1.24	.49	.58
	76	.50	.54	1.14	1.20	.50	.64
Wisconsin R. at Petenwell	73	.60	.40	1.20	1.16	.56	.62
	74	.53	.45	1.10	1.21	.53	.43
	75	.54	.56	1.11	1.12	.34	.47
	76	.56	.61	1.13	1.14	.56	.60

TABLE C-4. USGS MONITOR SITES SUMMARY OF DAILY RAINFALL CORRELATION ANALYSIS RESULTS

Monitor site*	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
MASSACHUSETTS							
Connecticut R. at W. Springfield (Thompsonville)	72	– ABORTED	–	–	–	–	–
	73	.60	.52	1.67	2.98	.80	.76
	74	.66	.47	1.32	1.21	.78	.81
	75	.63	.47	1.26	1.23	.81	.83
Chicopee R. at Chicopee Falls	73	– ABORTED	–	–	–	–	–
	74	.59	.60	1.30	1.16	.56	.45
	75	.56	.58	1.36	1.23	.41	.39
Westfield R. at Westfield	72	– ABORTED	–	–	–	–	–
	73	.56	.46	1.41	2.49	.74	.76
	74	.59	.45	1.27	1.28	.78	.80
	75	.63	.45	2.13	2.46	.81	.87
	76	.38	.45	1.64	1.84	.86	.82
MISSOURI							
Center Cr. near Carterville	72	.58	.50	1.67	1.71	.62	.55
	73	– ABORTED	–	–	–	–	–
	74	.64	.49	1.14	1.10	.59	.62
	75	.65	.50	1.14	1.15	.54	.54
	76	– ABORTED	–	–	–	–	–
James R. near Boaz	72	– ABORTED	–	–	–	–	–
	73	.64	.47	1.14	1.12	.57	.58
	74	.64	.54	1.13	1.13	.49	.48
	75	.65	.53	1.14	1.09	.44	.45
	76	.63	.52	1.11	1.11	.30	.28

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*Stations are grouped by state, states are in alphabetical order, stations are alphabetized within group; ABORTED indicates that less than 180 days of data were available that year.

(continued)

TABLE C-4 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
MISSOURI							
(continued)							
Wilsons Cr. near Battlefield	73	.55	.55	1.11	1.09	.12	.13
	74	.63	.56	1.08	1.10	.09	.10
	75	.62	.53	1.12	1.08	.14	.14
	76	.63	.52	1.06	1.05	.03	.04
Wilsons Cr. near	72	— ABORTED	—	—	—	—	—
Springfield	73	.58	.45	1.21	1.23	.61	.64
	74	.56	.46	1.24	1.18	.59	.64
	75	.67	.38	1.26	1.15	.61	.68
	76	.77	.43	1.24	1.16	.61	.64
NEW JERSEY							
Delaware R. at Trenton	72	.62	.46	1.79	5.35	.86	.87
	73	.57	.50	2.14	5.76	.87	.90
	74	.47	.46	2.05	3.07	.90	.90
	75	.52	.44	4.66	2.53	.92	.95
	76	.51	.51	2.91	4.58	.96	.95
OHIO							
Ashtabula R. at Ashtabula	72	.51	.51	1.29	1.35	.71	.67
	73	.58	.41	1.51	2.13	.77	.77
	74	.56	.47	1.41	1.34	.75	.72
	75	.63	.45	1.24	1.18	.70	.68
	76	.67	.42	1.22	1.24	.69	.68

(continued)

TABLE C-4 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit: Wetter than avg. days	Probability of greater than average DO deficit: Dryer than avg. days	Strength of DO deficit when deficit is greater than average: Wetter than avg. days	Strength of DO deficit when deficit is greater than average: Dryer than avg. days	Average percentage of saturation when deficit is worse than average: Wetter than avg. days	Average percentage of saturation when deficit is worse than average: Dryer than avg. days
OHIO (continued)							
Black R. at Elyria	70	– ABORTED	–	–	–	–	–
	71	– ABORTED	–	–	–	–	–
	72	– ABORTED	–	–	–	–	–
	73	.55	.50	1.55	1.64	.68	.53
	74	.52	.52	1.51	1.58	.59	.51
Blanchard R. near Findlay	72	.58	.57	1.79	2.65	.65	.67
	73	.65	.48	1.29	1.20	.65	.58
	74	.59	.52	1.14	1.10	.44	.43
	75	.62	.44	1.17	1.16	.50	.55
	76	.64	.49	1.22	1.19	.57	.59
Cuyahoga R. at Independence	72	.50	.54	1.20	1.16	.66	.61
	73	.60	.41	1.25	1.22	.72	.70
	74	.52	.49	1.15	1.15	.67	.62
	75	.57	.43	1.24	1.17	.74	.70
	76	.56	.39	1.20	1.14	.74	.74
Cuyahoga R. at Old Portage	72	.55	.42	1.71	1.40	.66	.66
	73	.57	.48	1.63	4.14	.74	.76
	74	.56	.43	1.30	1.34	.75	.76
	75	.58	.38	1.31	1.31	.68	.68
	76	.66	.44	1.27	1.19	.67	.75
Cuyahoga R. at W. 3rd St. Bridge	72	.59	.45	1.20	1.17	.41	.31
	73	.57	.46	1.12	1.09	.42	.35
	74	.55	.52	1.10	1.09	.43	.31
	75	.51	.45	1.14	1.12	.48	.34
	76	.53	.47	1.15	1.14	.42	.36

(continued)

TABLE C-4 (CONTINUED).

Monitor site	Water Year (19–)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO (continued)							
Grand R. near Painesville	75	.60	.59	1.19	1.16	.72	.66
	76	.54	.49	1.70	1.31	.69	.64
Grand R. at Painesville	72	.46	.51	1.45	2.10	.79	.74
	73	.54	.49	1.45	1.37	.81	.68
	74	.46	.48	1.23	1.23	.71	.57
Little Miami R. at Miamiville (Milford)	71	— ABORTED	—	—	—	—	—
	72	.41	.44	2.32	2.08	.85	.81
	73	.56	.42	1.50	2.22	.85	.84
	74	.53	.43	1.47	1.49	.83	.86
Little Miami R. near Spring Valley	72	.59	.37	1.17	1.13	.65	.61
	73	.53	.36	1.31	1.43	.70	.70
	74	.60	.43	1.27	1.21	.73	.74
	75	.61	.43	1.17	1.14	.74	.75
	76	.58	.38	1.19	1.16	.65	.66
Mad R. near Dayton	72	.66	.43	1.20	1.14	.72	.70
	73	.64	.34	1.26	1.14	.78	.78
	74	.60	.45	1.17	1.13	.73	.72
	75	.63	.41	1.20	1.20	.74	.75
	76	.65	.45	1.21	1.15	.68	.70
Mahoning R. at OH.-PA. State Line below Lowellville	72	.49	.50	1.15	1.16	.42	.37
	73	.56	.50	1.17	1.32	.53	.52
	74	.51	.49	1.16	1.12	.56	.49
	75	.59	.45	1.09	1.10	.57	.52
	76	.60	.44	1.18	1.14	.54	.52

(continued)

TABLE C-4 (CONTINUED).

Monitor site	Water Year (19--)	Probability of greater than average DO deficit		Strength of DO deficit when deficit is greater than average		Average percentage of saturation when deficit is worse than average	
		Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days	Wetter than avg. days	Dryer than avg. days
OHIO (continued)							
Sandusky R. near Upper Sandusky	72	.58	.43	1.89	5.08	.74	.83
	73	.56	.47	1.84	1.68	.79	.78
	74	.62	.45	1.77	–	.71	.70
	75	.62	.41	1.38	2.62	.70	.74
	76	.69	.42	1.40	1.21	.71	.75
Scioto R. at Chillicothe	72	– ABORTED	–	–	–	–	–
	73	– ABORTED	–	–	–	–	–
	74	.53	.49	1.14	1.13	.51	.52
	75	.56	.47	1.20	1.17	.48	.57
	76	.60	.39	2.15	1.31	.54	.58
OREGON							
South Umpqua near Brockway	72	.49	.46	1.85	2.88	.90	.84
	73	.51	.42	15.62	5.49	.93	.84
	74	.40	.47	3.07	1.86	.95	.80
	75	– ABORTED	–	–	–	–	–
	76	– ABORTED	–	–	–	–	–
PENNSYLVANIA							
Lehigh R. at Easton (Glendon)	72	.67	.51	1.35	1.56	.77	.76
	73	.62	.45	1.50	1.60	.83	.82
	74	.57	.54	1.52	4.98	.77	.75
	75	.61	.47	1.37	1.34	.77	.77
	76	.65	.47	1.42	1.96	.81	.83

APPENDIX D

RESULTS OF DETAILED SITE ANALYSES

This appendix contains the results of the detailed site analyses. These analyses were performed at 30 sites where a 60 percent or greater probability existed of a high flow or rainfall event occurring at the same time as a low dissolved oxygen event. The sites are grouped by state. The states are in alphabetical order within each state group.

Each site analysis contains some or all of the following:

- water quality monitor site name;
- monitor location, latitude and longitude, agency I.D. number;
- flow gage site name;
- flow location, latitude and longitude, agency I.D. number;
- rain gage location, I.D. number;
- short summary of daily correlation results;
- assessment of record quality;
- discharge, drainage area and population description;
- Streeter-Phelps analysis results;
- conclusions and comments; and
- daily or hourly plots of data from years with positive correlation.

Three types of illustrations are included in this appendix. Streeter-Phelps analysis results are presented as plots of DO deficit (mg/l) versus distance (miles) downstream of the urban area. Two lines generally appear on each illustration. The lower line depicts the deficit due to "normal" flows and the second line depicts the deficit due to "storm" flows. The saturation DO level for typical conditions is also illustrated. Important features such as the stream gage and DO monitor location as well as sewage treatment facilities are identified. The second type of illustration is the hourly data analysis. Two separate graphs are included in each illustration. The upper graph illustrates absolute DO level and saturation DO level (both in mg/l) versus time in days. The lower graph presents the stream flow, DO deficit, and rainfall. The flow line has been normalized by dividing the actual flow values by the average value for the entire period illustrated. This preserves the hydrograph shape and avoids rescaling the graph for every new station. The rainfall is shown as hourly histograms (vertical rectangular bars). The format of the illustrations allows fairly easy visualization of the relationship between the several variables. The final illustration type is the daily average value plots. These generally illustrate either flow in cubic feet per second versus time in days or DO and DO deficit in mg/l versus time in days.

STATE: MASSACHUSETTS

Monitor Name: Connecticut River at West Springfield
USGS I.D.: 01 177 200 Latitude: 42 05 46 Longitude: 72 35 43

Stream Gage Name: Connecticut River at Thompsonville, Conn.
USGS I.D.: 01 184 000 Latitude: 41 59 14 Longitude 72 36 21

Rain Gage Name: Springfield
Weather Bureau I.D.: 8046

Daily Data Analysis Results: Water years 72-75 were examined. The probability of low dissolved oxygen with high flow averaged 40 percent. The probability of low dissolved oxygen on days with rainfall was greater than 60 percent in 1973, 1974, and 1975. Dissolved oxygen levels remained around the 75-80 percent of saturation level on days with rain.

Quality of Records: The monitor is visited once a month or more. Record is reliable except for two to three weeks each summer.

Discharge Characteristics: Average flow 16,250 cfs, approx. range 1,000 to 100,000 cfs

Drainage Area at Monitor: 9,623 square miles

Urban Area(s) Contributing at Monitor: Turners Falls, Northampton, Holyoke, Chicopee
approximate population (Almanac) 87,500

Approximate Urban Area Contributing at Monitor: 60 sq mi or less than 1 percent of total

Results of Streeter-Phelps Analysis: Monitor is located satisfactorily for normal flows. At high flows a location 20 to 30 miles downstream would be better. Storm flow could produce D.O. deficits of 4.5 mg/l resulting in D.O. levels below 5 mg/l during storm events. There is some evidence of this on daily plots. Simulation results follow in Figure D-1.

Hourly Data Analysis Results: The period examined illustrates a mild tendency for the deficit to decrease slowly during the flow event. Water quality is never very bad at this site. The period of hourly data is illustrated in Figure D-2.

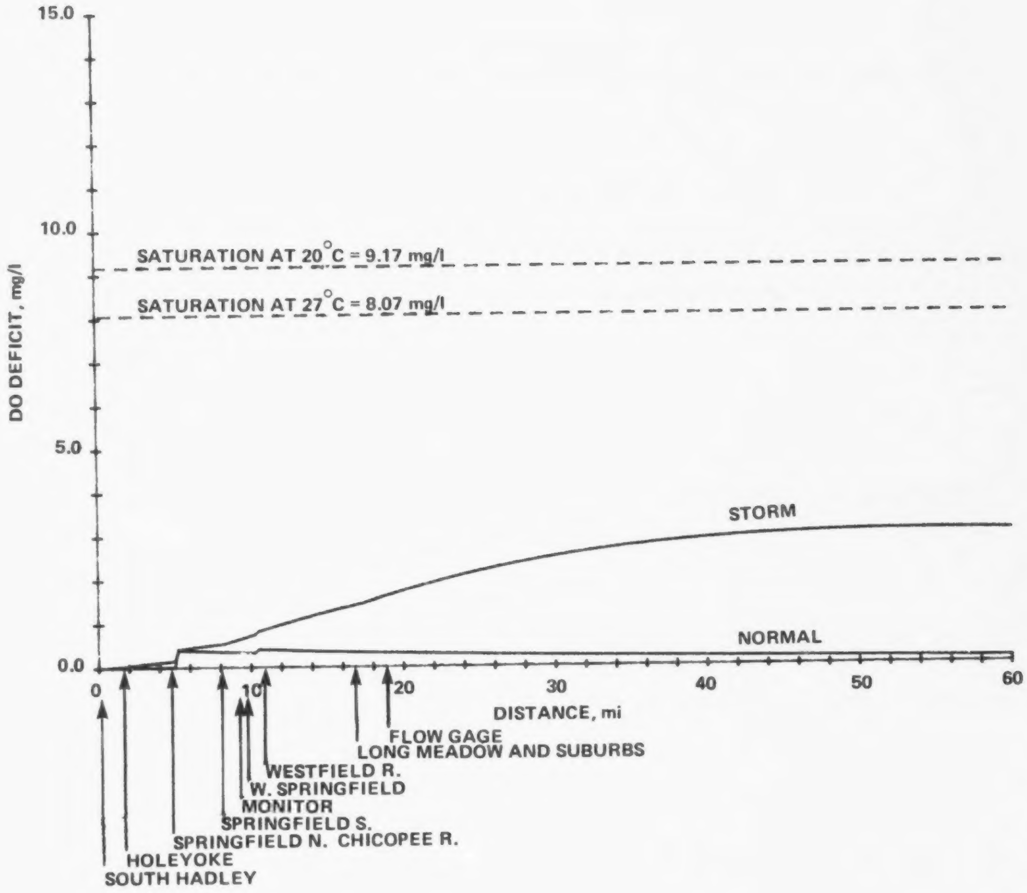

Figure D-1. Streeter-Phelps analysis results for Connecticut R. at West Springfield, MA.

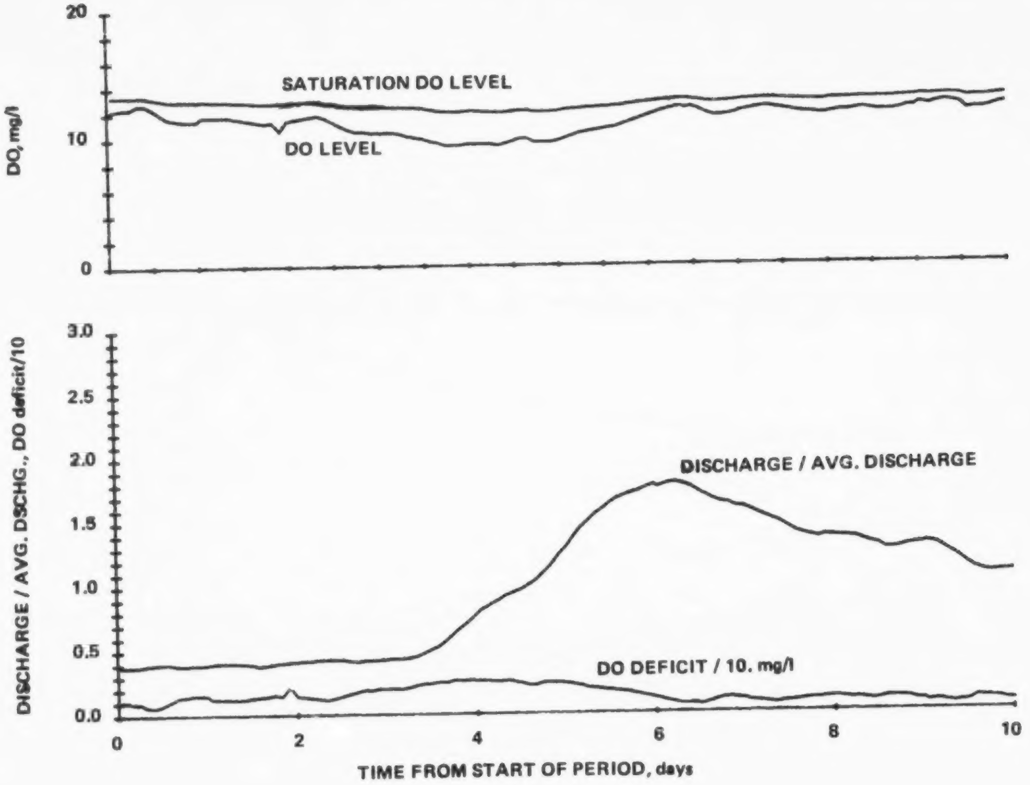

Figure D-2. Hourly data for Connecticut R. at W. Springfield, MA. (4/1/74 to 4/10/74).

Conclusions and Comments: During June 1974, there appears to have been a period when the D.O. dropped drastically during a flow event. The monitor quit during the most interesting time. This site does not appear to have a water quality problem attributable to urban runoff. It would be interesting, however, to put a monitor at the theoretical D.O. sag point and see what was observed then.

STATE: MASSACHUSETTS

Monitor Name: North Nashua River near Lancaster
USGS I.D.: 01 094 700 Latitude: 42 28 47 Longitude: 71 41 04

Stream Gage Name: North Nashua River near Leominster
USGS I.D.: 01 094 500 Latitude: 42 30 06 Longitude: 71 43 23

Rain Gage: Fitchburg 4 SE
Weather Bureau I.D.:

Daily Data Analysis Results: Water years 1968-72 were examined. The probability of low dissolved oxygen with high flow exceeded 60 percent in 1970 and the summer of 1971. Daily rainfall correlation was not run at this station. Hourly rainfall data were used in the detailed analysis, however. Dissolved oxygen levels are definitely low, averaging less than 60 percent of saturation most of the time and falling to 40-50 percent during wet weather.

Quality of Records: Monitor is visited once a month or more. Record is highly reliable for flow and good for the monitor except for short periods scattered throughout the year.

Discharge Characteristics: Average flow approximately 175 cfs, approx. range 50-1,000 cfs

Drainage Area at Monitor: 128 square miles

Urban Area(s) Contributing at Monitor: Fitchburg, Leominster, approximate population: 43,300 and 33,000, respectively

Approximate Urban Area Contributing at Monitor: 11 mi^2 (based on $7100/mi^2$) or 9 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: The period examined had a definite tendency for the D.O. deficit to increase at the beginning of a storm event. The D.O. level dropped from an average of over 6 mg/l to less than 5 and remained there for one day. The average D.O. level was definitely worse during the flow events examined. The period of hourly data is illustrated in Figure D-3. The EPA suggested standard of 2.0 mg/l for 4.0 hours was violated on the third and fourth days of the period examined.

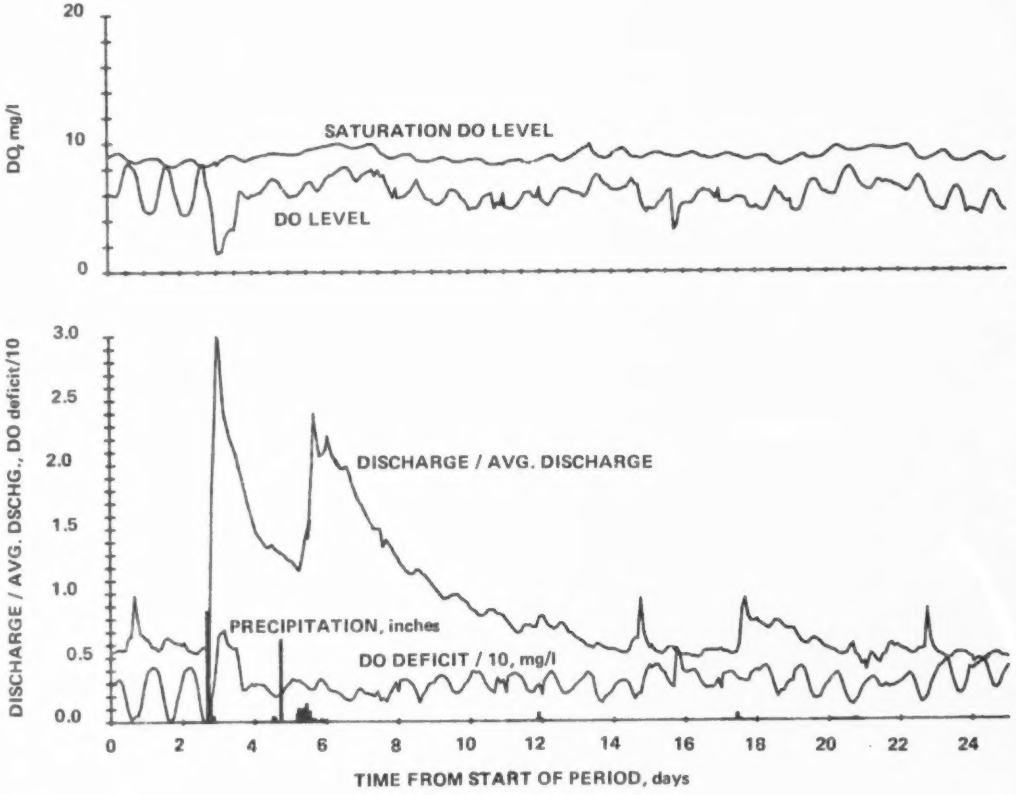

Figure D-3. Hourly data for N. Nashua R. near Leominster, MA. (6/1/70 to 6/25/70).

Conclusions and Comments: A definite problem exists here. The monitor is 5 miles downstream of the Leominster Sewage Treatment Plant. It is 10 miles below the town. This probably puts it in an excellent position to sense a D.O. sag. It is not possible without detailed examination of the site to tell whether the problem is urban runoff, combined sewer overflows, sediment entrainment, or some other problem.

STATE: MASSACHUSETTS

Monitor Name: Westfield River at West Springfield
USGS I.D.: 01 183 600 Latitude: 42 05 59 Longitude: 72 38 28

Stream Gage Name: Westfield River near Westfield
USGS I.D.: 01 183 500 Latitude: 42 06 24 Longitude: 72 41 58

Rain Gage: Springfield
Weather Bureau I.D.: 8046

Daily Data Analysis Results: Water years 1972-76 were examined. The probability of low dissolved oxygen with high flow reached 62 percent in 1975. The same year the probability of low D.O. on days with rainfall was 63 percent. Dissolved oxygen levels are not bad, running approximately 75 percent saturation most of the time.

Quality of Records: The monitor is visited once a month or more. Flow records are excellent. Monitor records are poor in the summer with entire months missing.

Discharge Characteristics: Average flow approx. 940 cfs, approx. range 100-13,000 cfs

Drainage Area at Monitor: 497 square miles

Urban Area(s) Contributing to Monitor: Pittsfield, Westfield, West Springfield
approximate populations: estimate 35-50,000

Approximate Urban Area Contributing at Monitor: 5 to 7 square miles or approximately 1 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: Hourly data could not be obtained for this site.

Conclusions and Comments: Examination of the daily record indicates a number of periods where the D.O. level appears to drop at the time of flow events. The monitor is poorly located. The "problem" may originate at Pittsfield which is 40 miles upstream. A monitor closer to there might have detected more. The water quality is generally good at this site.

STATE: MISSOURI

Monitor Name: Center Creek near Carterville
USGS I.D.: 07 186 400 Latitude: 37 08 26 Longitude: 94 22 57

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Springfield
Weather Bureau I.D.: 8046

Daily Data Analysis Results: Water years 1972-76 were examined. The probability of low dissolved oxygen with high flow never exceeded 53 percent. The probability of low dissolved oxygen on days with rainfall reached 64 percent in 1974 and 65 percent in 1975. Dissolved oxygen levels in general are low ranging from 45 to 60 percent of saturation.

Quality of Records: The monitor was visited once a month or more. Monitor records are excellent with only a few short periods per year missing.

Discharge Characteristics: Average flow 200 cfs, approx. range 10 to 37,000 cfs.

Drainage Area at Monitor: 232 square miles

Urban Area(s) Contributing at Monitor: Perhaps a little of Carthage and the fringes of Joplin, approx. population - not determined.

Approximate Urban Area Contributing at Monitor: 2 or 3 square miles at most or less than 1 percent of total.

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: No hourly data were obtained at this site.

Conclusions and Comments: Very little urban area seems to contribute at monitor. Correlation is with rain gage 60 miles away. Examination of daily record seems to indicate isolated events where D.O. decreases with flow. This does not seem to be related to urban runoff. There is a great deal of strip mining between the monitor and Joplin.

STATE: MISSOURI

Monitor Name: James River near Boaz, Missouri
USGS I.D.: 07 052 250 Latitude: 37 00 25 Longitude: 93 21 50

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Springfield
Weather Bureau I.D.: 7976

Daily Data Analysis Results: Water years 1972-76 were examined. The probability of low dissolved oxygen with high flow never exceeded 44 percent. The probability of low dissolved oxygen on days with rainfall exceeded 60 percent in 1973, 74, 75, and 76. The correlation could be clearly seen by eye. Dissolved oxygen levels were extremely low, ranging from 23 to 60 percent saturation.

Quality of Records: Rated fair by USGS, monitor is visited once a month. Flow record is continuous, monitor looses from 1 to 2 months a year, usually at summer low flow.

Discharge Characteristics: Average flow approx. 300 cfs, approx. range 55 to 31,500 cfs.

Drainage Area at Monitor: 462 square miles

Urban Area(s) Contributing at Monitor: Springfield, approx. population 180,000.

Approximate Urban Area Contributing at Monitor: 25 square miles or 5 percent of the total

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: Hourly data were not available for this site.

Conclusions and Comments: The James River receives treated sewage from the Springfield Southwest sewage treatment plant. It also receives the flow from Wilsons Creek which is very low in D.O. There is a definite D.O. problem here, but whether it is direct urban runoff or something else is hard to say. The dissolved oxygen level is typically below 5 mg/l 4 months of every year.

STATE: MISSOURI

Monitor Name: Wilsons Creek near Battlefield
USGS I.D.: 07 052 160 Latitude: 37 07 02 Longitude: 93 24 14

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Springfield
Weather Bureau I.D.: 7976

Daily Data Analysis Results: Water years 1973-76 were examined. The probability of low dissolved oxygen at the time of a flow event never exceeded 60 percent but did reach 57 percent in 1976. The probability of low D.O. on days with rainfall exceeded 60 percent in 1974, 75, and 76. Dissolved oxygen levels are very low, ranging from 2 to 16 percent of saturation.

Quality of Records: Monitor is visited once a month or more. Flow record is generally continuous. Monitor record is intermittent during the summer months.

Discharge Characteristics: Average flow approx. 100 cfs, approx. range 25-4,000 cfs.

Drainage Area at Monitor: 55 square miles.

Urban Area(s) Contributing at Monitor: Springfield, approx. population 180,000.

Approximate Urban Area Contributing at Monitor: 25 square miles or 45 percent of total.

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: Hourly data could not be obtained for this site.

Conclusions and Comments: The problem at this site is connected to the problem at Wilsons Creek near Springfield, Missouri. Hourly data were examined there and may be seen by referring to that station. The problem is no doubt related to the fact that Springfield is nearly 1/2 of the drainage basin.

STATE: MISSOURI

Monitor Name: Wilsons Creek near Springfield
USGS I.D.: 07 052 100 Latitude: 37 10 06 Longitude: 93 22 14

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Springfield
Weather Bureau I.D.: 7976

Daily Data Analysis Results: Water years 1972-76 were examined. The probability of low dissolved oxygen with high flow exceeded 70 percent in 1973, 75, and 76. It hit a peak of 81 percent in 1975. This is the highest probability encountered at any site examined. The probability of low D.O. on days with rainfall exceeded 60 percent in 1975 and 1976. D.O. levels are characteristically low, averaging 50 to 60 percent saturation.

Quality of Records: The monitor is visited once a month or more. Flow records are virtually continuous. The monitor quits from one to two months a year, usually at times of low flow.

Discharge Characteristics: Average flow approximately 20 cfs, range from 0 to 2800 cfs.

Drainage Area at Monitor: 31.4 square miles.

Urban Area(s) Contributing at Monitor: Springfield, approx. population 180,000.

Approximate Urban Area Contributing at Monitor: 25 square miles or 80 percent of total.

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: The hourly data periods examined are shown in Figures D-4, D-5 , and D-6. Water quality is very poor at all times, but definitely decreases more at times of high flow. The EPA suggested standard of 2.0 mg/l for 4.0 hours is violated several times in the periods examined.

Conclusions and Comments: This site had the highest percentage of urban drainage of any in the entire study. There can be no doubt that the large percentage of urban area contributes to the bad quality. It is not possible, however, to tell the exact cause of the low D.O. - high flow without physically examining the site.

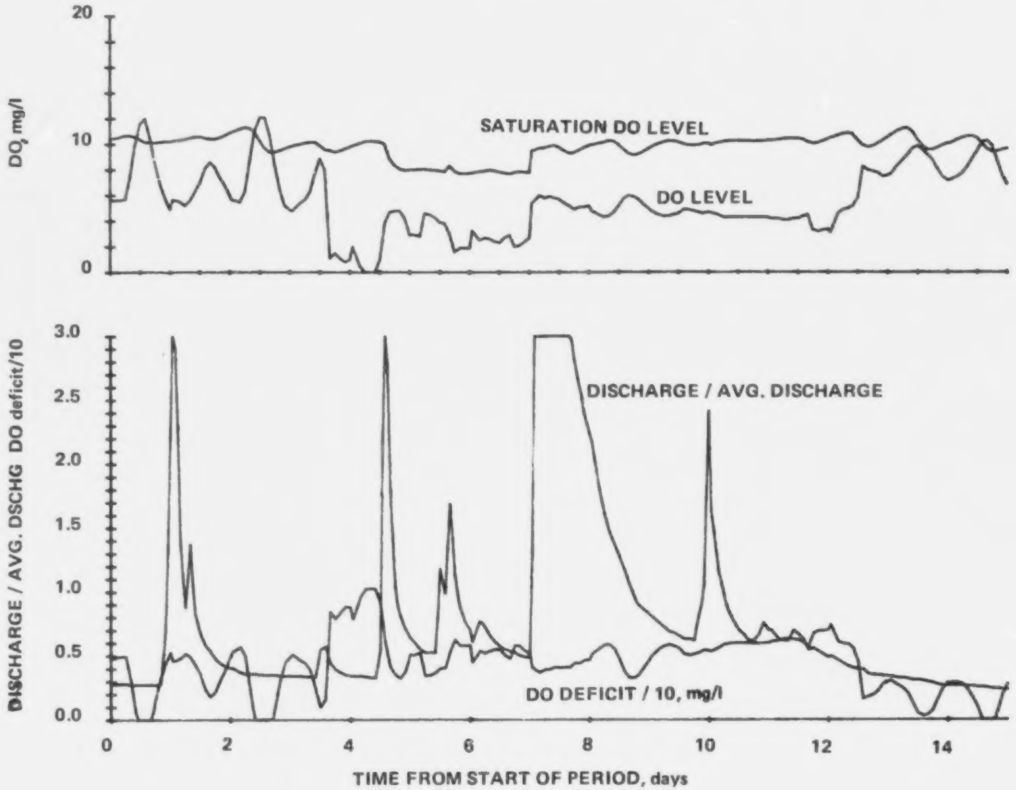

Figure D-4. Hourly data for Wilsons Cr. near Springfield, MO. (4/15/73 to 4/29/73).

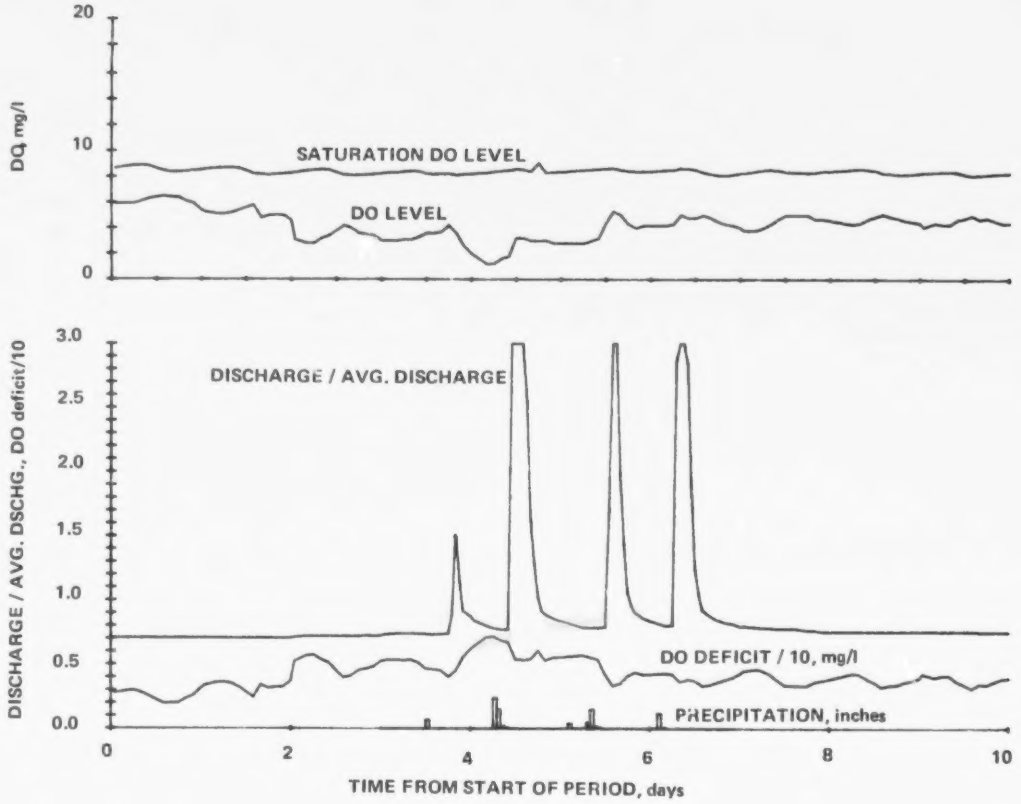

Figure D-5. Hourly data for Wilsons Cr. near Springfield, MO.
(8/10/75 to 8/19/75).

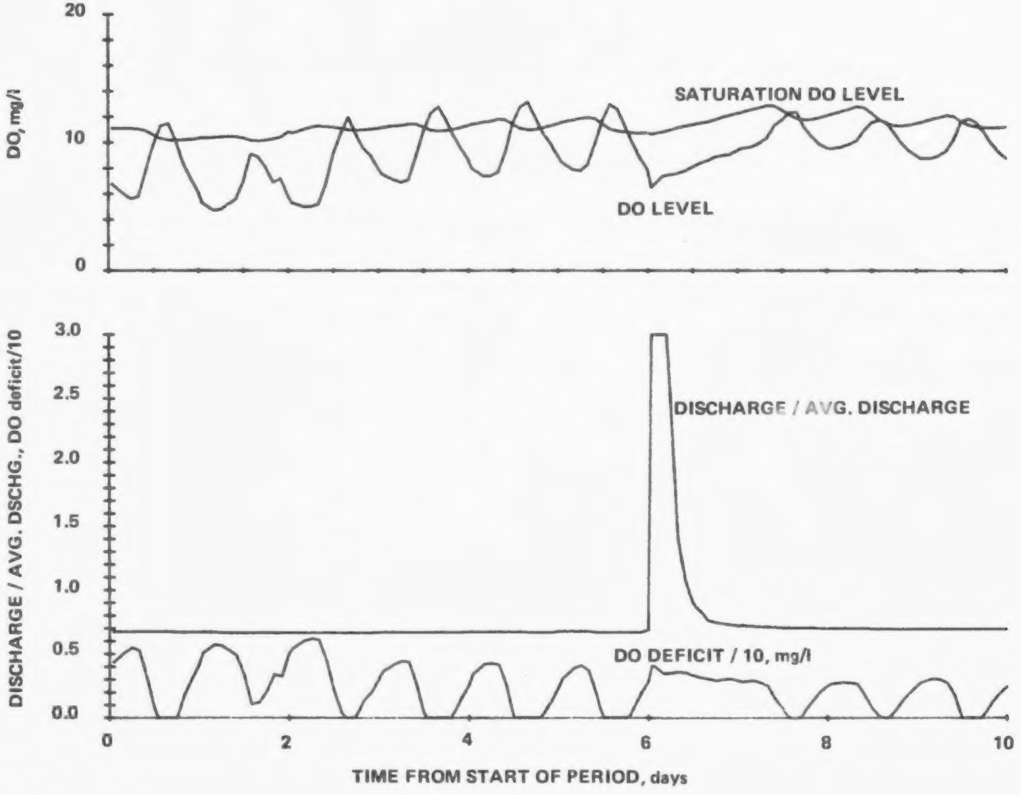

Figure D-6. Hourly data for Wilsons Cr. near Springfield, MO. (2/15/76 to 2/24/76).

STATE: NEW JERSEY

Monitor Name: Delaware River at Trenton
USGS I.D.: 01 463 500 Latitude: 40 13 18 Longitude: 74 46 42

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Trenton
Weather Bureau I.D.: 8883

Daily Data Analysis Results: Water years 1972-76 were examined. The probability of low D.O. with high flow exceeded 60 percent in 1973 and 1975. It reached 58 percent in 1972. The probability of low D.O. on days with rainfall exceeded 60 percent in 1972. It reached 57 percent in 1973 and 1976. Water quality here is generally good with D.O. levels from 85 to 97 percent saturation. The correlation between flow and low D.O. is so obvious that it can easily be seen by eye. This is illustrated in Figure D-7.

Quality of Records: The monitor is visited once a month or more. The flow record is virtually continuous. The monitor record is good overall but from two weeks to a month are missing each year.

Discharge Characteristics: Average flow 12,000 cfs, approx. range 1,200 to 325,000 cfs.

Drainage Area at Monitor: 6,780 square miles

Urban Area(s) Contributing at Monitor: Trenton and suburbs, population estimated at greater than 1/2 million.

Approximate Urban Area Contributing at Monitor: 60 to 70 square miles or 1 percent of total.

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: Hourly data could not be obtained at this site.

Conclusions and Comments: Trenton, New Jersey marks the upstream edge of an urban megalopolis. The water quality in the Delaware deteriorates rapidly downstream. See for example Delaware at Chester and Bristol, Pennslyvania. While the water quality is good at Trenton, it is definitely not good as one proceeds downstream. The fact that such a strong correlation exists at Trenton makes one wonder what would have been measured on a smaller stream.

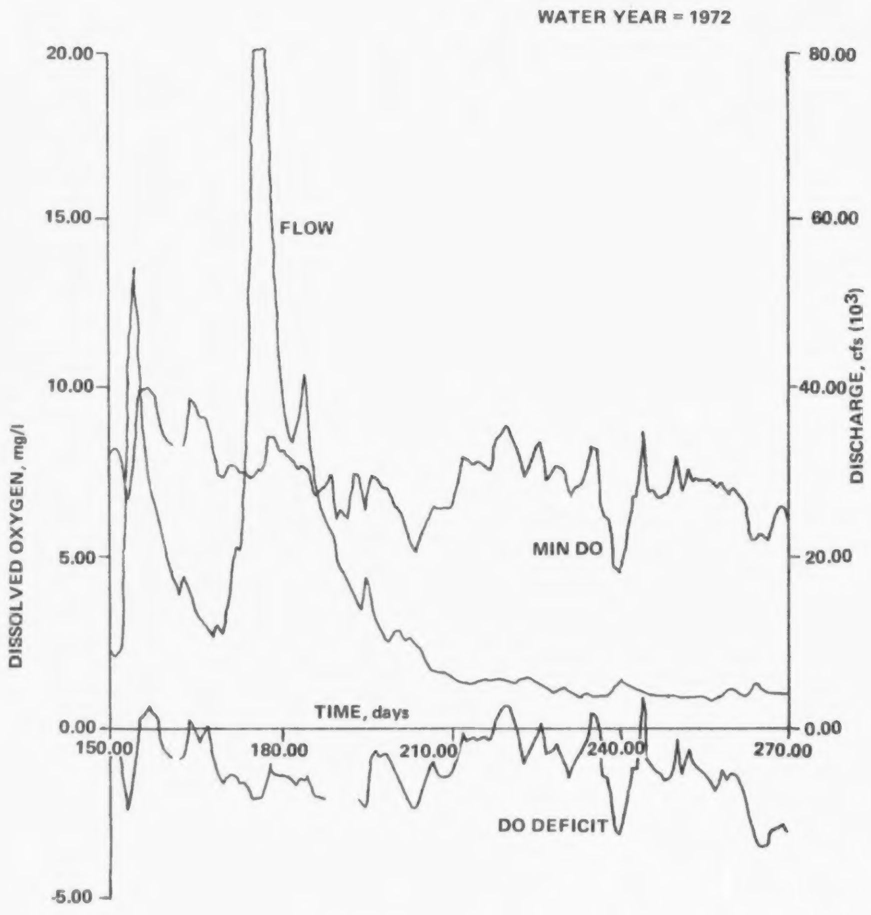

Figure D-7. Daily DO and flow for Delaware R. at Trenton, NJ.

The monitor is downstream of Trenton on the New Jersey shore. It is in a good place to sense urban runoff before it mixes laterally across the stream. It is much too close to Trenton to sense a fully developed D.O. sag. No water quality standards violations were seen here.

STATE: NEW JERSEY

Monitor Name: Manasquan River at Squankum
USGS I.D.: 01 408 000 Latitude: 40 09 47 Longitude: 74 09 21

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage:
Weather Bureau I.D.:

Daily Data Analysis Results: Water years 1970-74 were examined. The probability of low D.O. at high flow exceeded 60 percent in 1971 and 1972. No daily rainfall correlation was performed at this site. D.O. levels are generally low ranging from 50 to 70 percent saturation. The daily record for 1972 is illustrated in Figure D-8.

Quality of Records: USGS rates the flow record as excellent. The monitor is visited at least once a month. Monitor data is fairly typical with from two to four weeks missing each year.

Discharge Characteristics: Average flow 75 cfs, approx. range 13 to 3,000 cfs.

Drainage Area at Monitor: 43.4 square miles

Urban Areas Contributing at Monitor: Farmingdale, Naval Reserve Ammunition Dump, several unnamed suburbs, population unknown.

Approximate Urban Area Contributing at Monitor: 1-2 square miles or 2-4 percent of total.

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: Not performed at this site.

Conclusions and Comments: Very little urban area could be found here. There is a good deal of swamp upstream of the monitor. This may lend some additional evidence to the swamp flushing theory advanced by the Triangle J208 Study (3). The water quality is definitely bad and there is an obvious correlation with flow events. The problem, however, does not appear to be related to the objectives of this study.

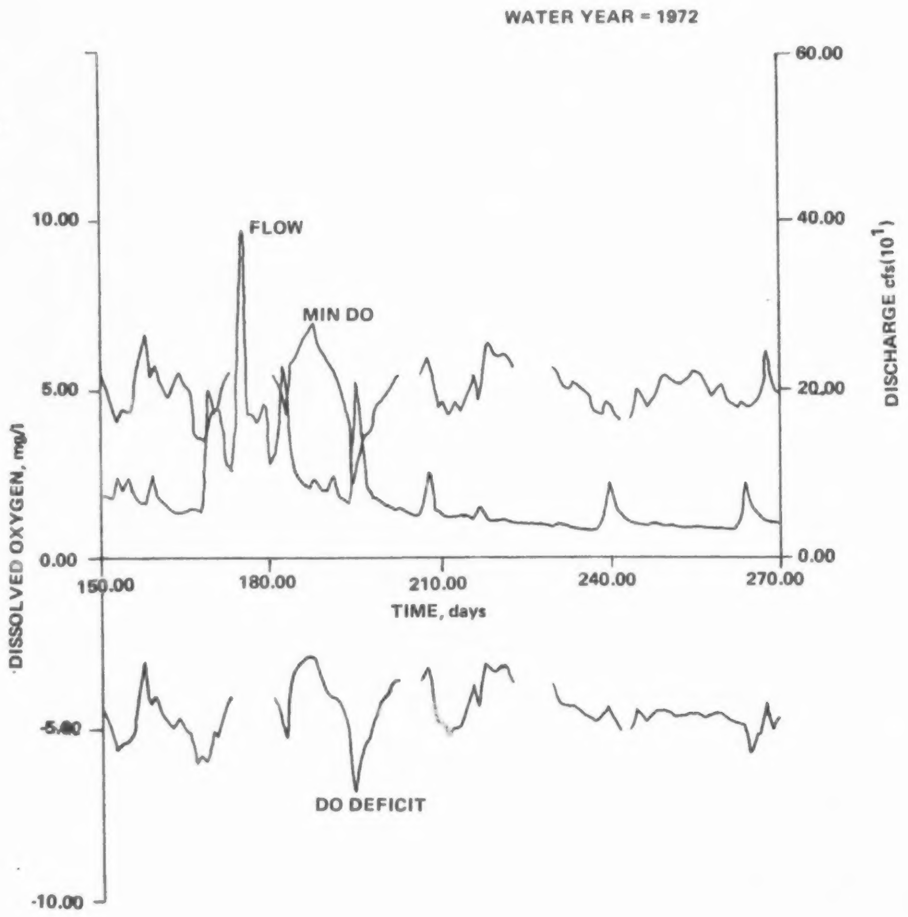

Figure D-8. Daily DO and flow for Manasquan R. at Squankum, NJ.

STATE: NEW JERSEY

Monitor Name: Raritan River near South Bound Brook
USGS I.D.: 01 404 100 Latitude: 40 30 47 Longitude: 74 32 24

Stream Gage Name: Raritan River Below Calco Dam at Bound Brook
USGS I.D.: 01 403 060 Latitude: 40 33 05 Longitude: 74 32 54

Rain Gage: Bound Brook
Weather Bureau I.D.: 0927

Daily Data Analysis Results: Water years 1974 and 1975 were examined. The probability of low D.O. at high flow reached 60 percent in 1975. D.O. levels were generally high, ranging from 75 to 80 percent saturation. The daily data for 1975 is illustrated in Figure D-9. Several obvious instances where the D.O. decreased with flow events were found. Just as many times can be found when the opposite is true.

Quality of Records: Much of the 1974 D.O. record was missing. The flow record is excellent. The 1975 monitor record is good except for the winter months. The monitor is visited once a month or more.

Discharge Characteristics: Average flow 1250 cfs, approx. range 1,000 to 17,000 cfs.

Drainage Area at Monitor: 862 square miles

Urban Area(s) Contributing at Monitor: Somerville, Bound Brook, Middlesex, Manville, South Bound Brook, approximate population 47,000.

Approximate Urban Area Contributing at Monitor: 6.63 square miles or 1 percent of total.

Results of Streeter-Phelps Analysis: The results of the analysis are illustrated in Figure D-10. The monitor location is too close to the urban area to sense maximum. sag. A location 10 miles or more downstream would be better.

Hourly Data Analysis Results: Hourly data could not be obtained for this site.

Conclusions and Comments: Water quality is not good here. There are 6 sewage treatment plants along the reach immediately above the monitor. The entire area is heavily industrialized. The monitor is too close to the urban area to sense the maximum sag in a Streeter-Phelps sense.

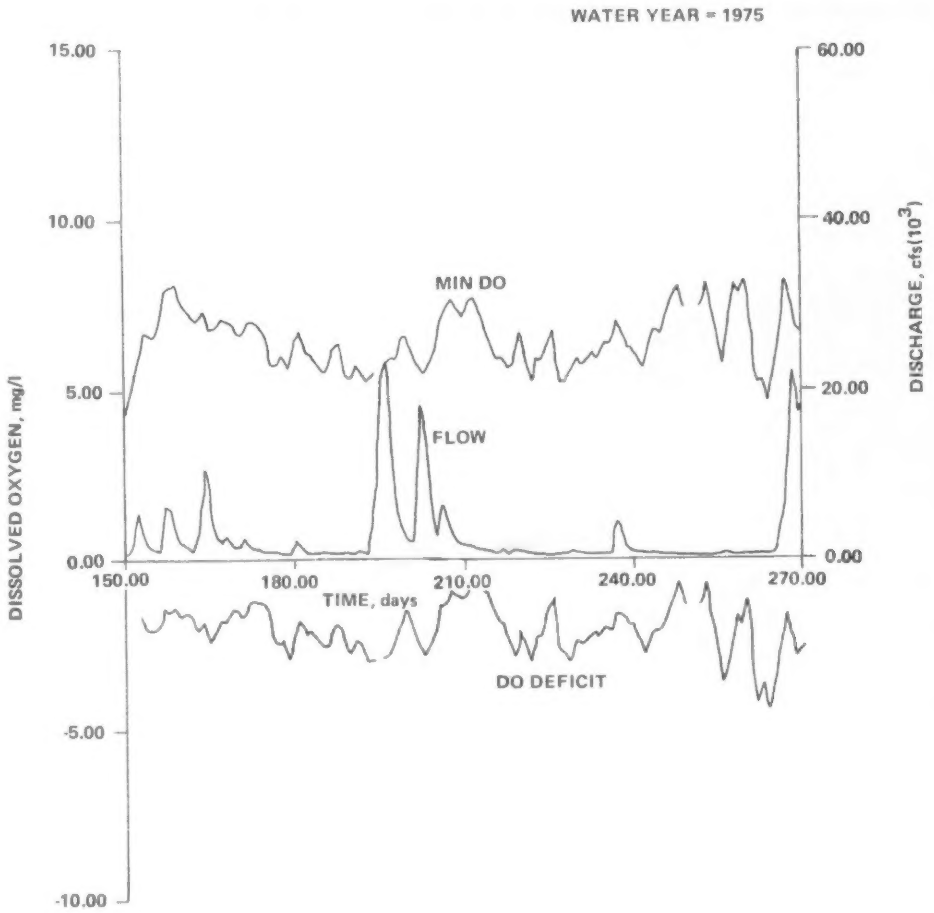

Figure D-9. Daily DO and flow for Raritan R. near South Bound Brook, NJ.

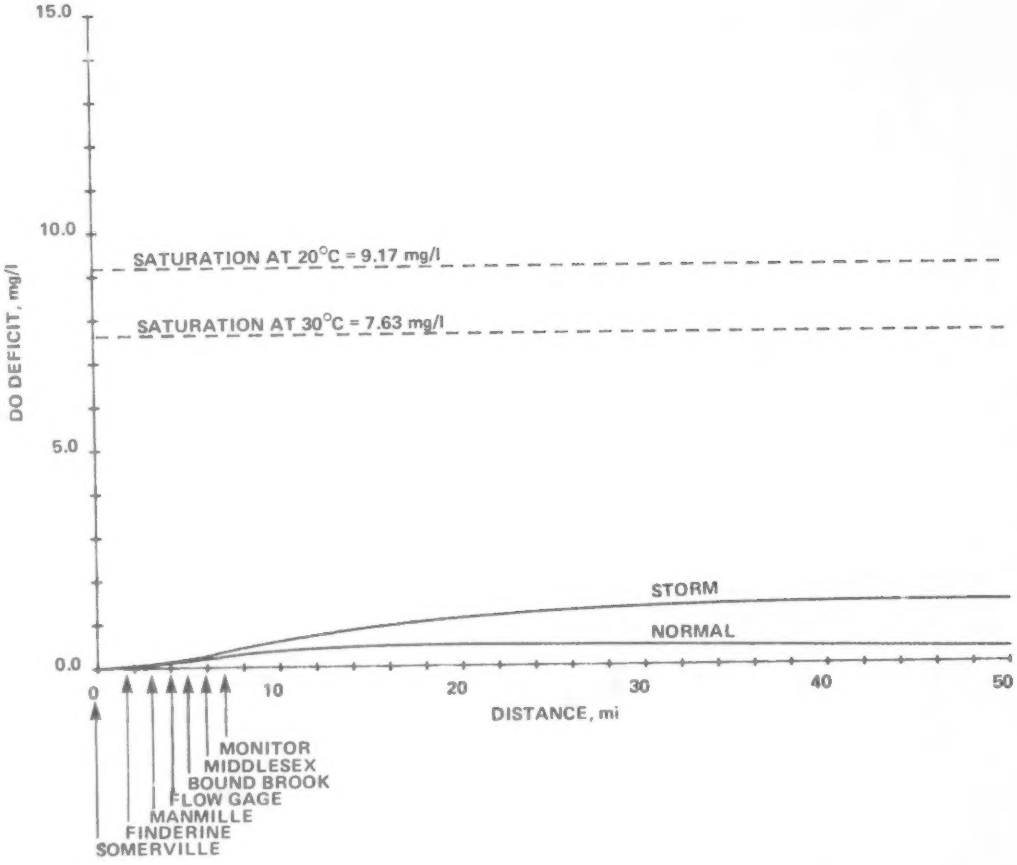

Figure D-10. Streeter-Phelps analyses results for Raritan R. near South Bound Brook, NJ.

STATE: OHIO

Monitor Name: Ashtubula River at Ashtabula
USGS I.D.: 04 212 700 Latitude: 41 54 00 Longitude: 80 47 44

Stream Gage Name: Ashtabula River near Ashtabula
USGS I.D.: 04 212 500 Latitude: 41 51 20 Longitude: 80 45 44

Rain Gage: Ashtabula
Weather Bureau I.D.: 0264

Daily Data Analysis Results: Water years 1972-76 were examined. The probability of low D.O. with high flow reached 60 percent in 1975. The probability of low D.O. on days with rainfall exceeded 60 percent in 1975 and 1976. Dissolved oxygen levels are in the 65 to 70 percent saturation range.

Quality of Records: The monitor is visited once a month or more. Both the flow and monitor records are excellent with little missing data.

Discharge Characteristics: Average flow 150 cfs, approx. range 0-10,000 cfs.

Drainage Area of Monitor: 136 square miles

Urban Area(s) Contributing at Monitor: Ashtabula, Harbor, East Ashtabula, approximate population 64,000

Approximate Urban Area Contributing at Monitor: 9 square miles or 7 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site - river empties into Lake Erie less than one mile downstream.

Hourly Data Analysis Results: The period examined shows a definite tendency for the D.O. to improve with increased flow. Water quality is poor here with D.O. less than 5 mg/l during much of the summer. The hourly data are illustrated in Figure D-11.

Conclusions and Comments: The lower reaches of the Ashtabula are probably more like an estuary than a river. There is a heavy industrial concentration near the monitor. Poor water quality does not appear directly related to urban surface runoff.

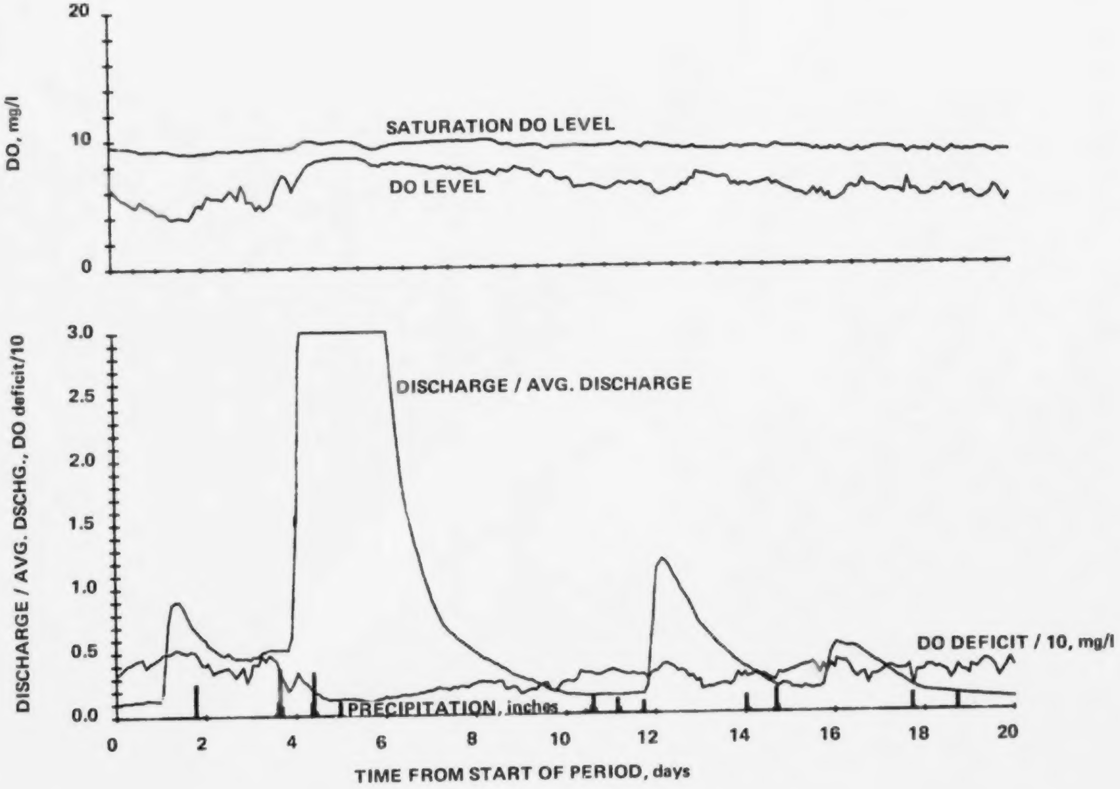

Figure D-11. Hourly data for Ashtabula R. near Ashtabula, OH.
(6/1/75 to 6/20/75).

STATE: OHIO

Monitor Name: Blanchard River near Findlay
USGS I.D.: 04 189 000 Latitude: 41 03 21 Longitude: 83 41 17

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Findlay STP
Weather Bureau I.D.: 2791

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. with high flow never exceeded 55 percent. The probability of low D.O. on days with rainfall exceeded 60 percent in 1973, 1975, and 1976. Water quality levels are generally poor, ranging from 40 to 70 percent D.O. saturation.

Quality of Records: Both the monitor and flow records are excellent. Virtually, no data are missing from either. The monitor is visited once a month or more.

Discharge Characteristics: Average flow 250 cfs, approx. range 10 to 15,000 cfs

Drainage Area at Monitor: 346 square miles

Urban Area(s) Contributing at Monitor: Findlay, approximate population 38,200

Approximate Urban Area Contributing at Monitor: 7 square miles or 2 percent of total

Results of Streeter-Phelps Analysis: Results of the analysis indicates that the monitor is too close to Findlay to sense the maximum deficit. A location 8 to 10 miles downstream would be better. The results of the analysis are illustrated in Figure D-12.

Hourly Data Analysis Results: The period examined seemed to indicate a correlation between the presence of rainfall and higher than average D.O. deficit. High flow appears to decrease the deficit. Water quality is poor with many days below 5 mg/l D.O. Given the monitor location this may actually be a case of urban runoff caused D.O. deficit. The hourly data are illustrated in Figure D-13.

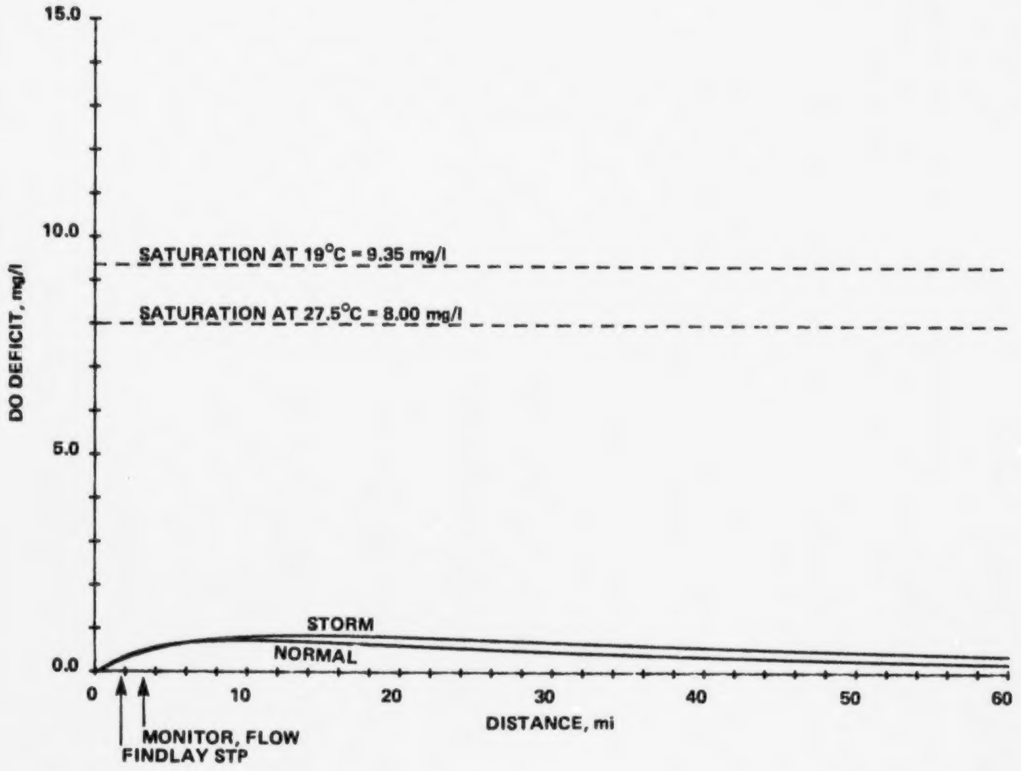

Figure D-12. Streeter-Phelps analysis results for Blanchard R. near Findlay, OH.

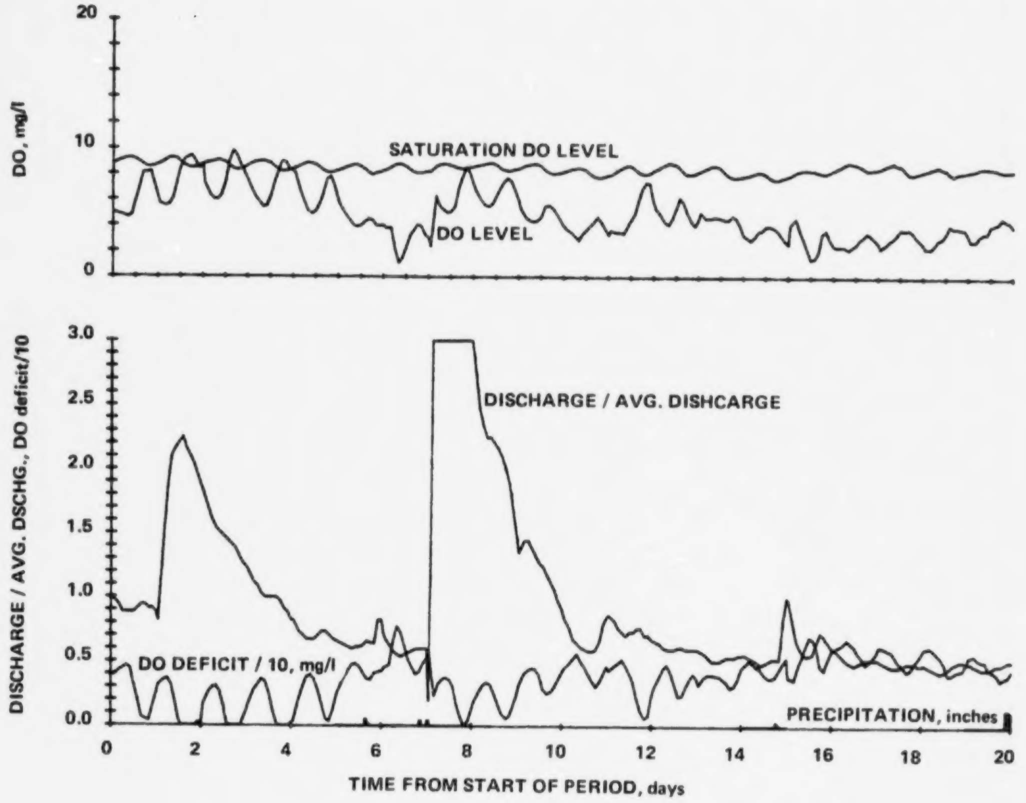

Figure D-13. Hourly data for Blanchard R. near Findlay, OH. (7/1/76 to 7/20/76).

Conclusions and Comments: This would be an interesting site to study in detail. It is hydraulically simple. Findlay is the only urban area. The monitor is 1.5 miles downstream of the sewage treatment plant. Sediment records are available. There is some strip mining and considerable oil activity in the area. Ohio State University examined this site in an independent effort and concluded that poor treatment facilities were part of the problem. They concluded that it would be difficult to separate the CSO effects from just plain bad treatment effluent.

STATE: OHIO

Monitor Name: Cuyahoga River at Independence
USGS I.D.: 04 208 000 Latitude: 41 23 43 Longitude: 81 37 48

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Cleveland WB APT
Weather Bureau I.D.: 1657

Daily Data Analysis Results: Water year 1972-1976 were examined. The probability of low D.O. with high flow never exceeded 60 percent. The probability of low D.O. on days with rainfall exceeded 60 percent in 1973 and 1976. Water quality levels are in the range 60 to 70 percent of saturation.

Quality of Records: The monitor is visited once a month or more. Both the flow and monitor records are virtually continuous with little or no missing values.

Discharge Characteristics: Average flow approx. 800 cfs, range 55 to 25,000 cfs

Drainage Area at Monitor: 707 square miles

Urban Area(s) Contributing at Monitor: Cleveland suburbs, Akron, approximate population 2,500,000+

Approximate Urban Area Contributing at Monitor: 60 square miles counting Akron or 8 percent of total, 110 square miles counting Cleveland suburbs or 16 percent of total.

Results of Streeter-Phelps Analysis: The analysis indicates that the monitor is in a good place to sense a sag due to influences at Akron. The analysis indicates that storm flow at Akron could drive the D.O. at Independence to zero. The results are shown in Figure D-14.

Hourly Data Analysis Results: The period examined showed a definite tendency for the D.O. deficit to increase at high flow and on days with rain. The problem was not overly severe for the period investigated with D.O. levels averaging 6 mg/l. This is shown in Figure D-15.

Conclusions and Comments: This would be a reasonably good site to study in detail. The lower reaches of the Cuyahoga are famous in water quality annuals for catching fire in the early 1960s. Sediment records are available here. The urban percentage is large and the monitor is well located.

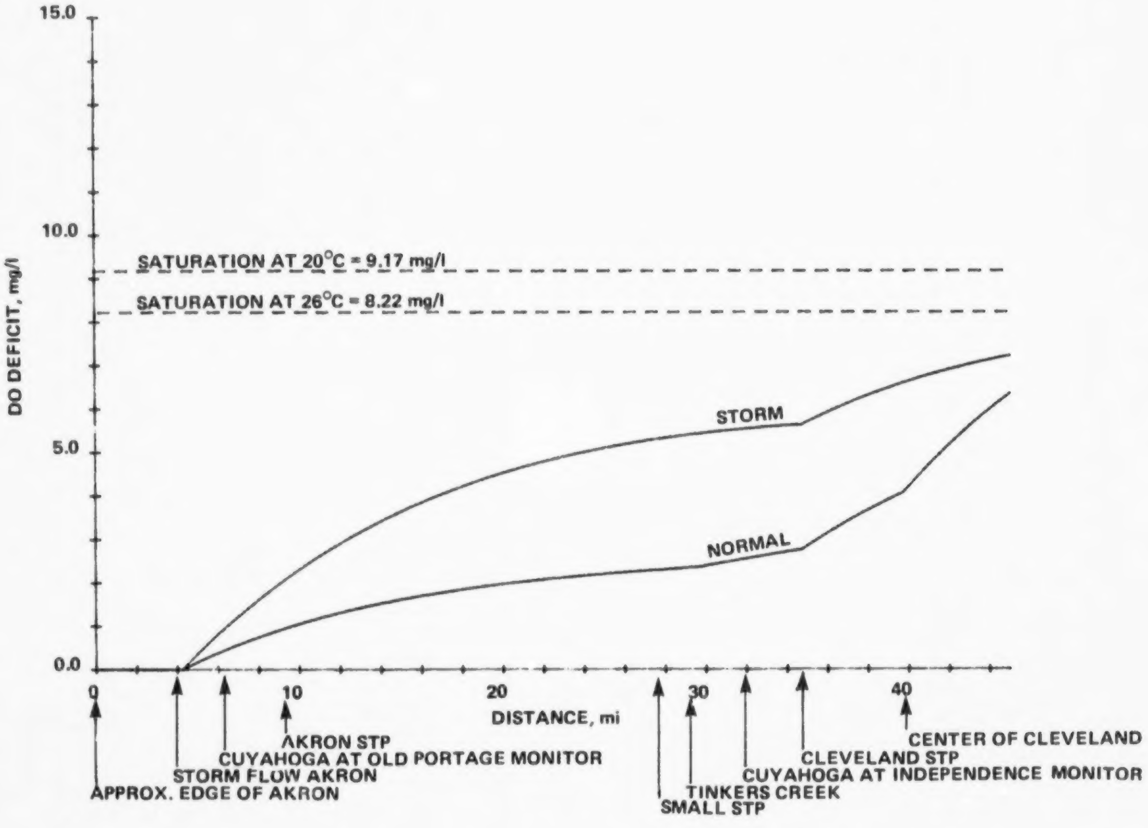

Figure D-14. Streeter-Phelps analysis results for Cuyahoga R. from Akron to Cleveland, OH.

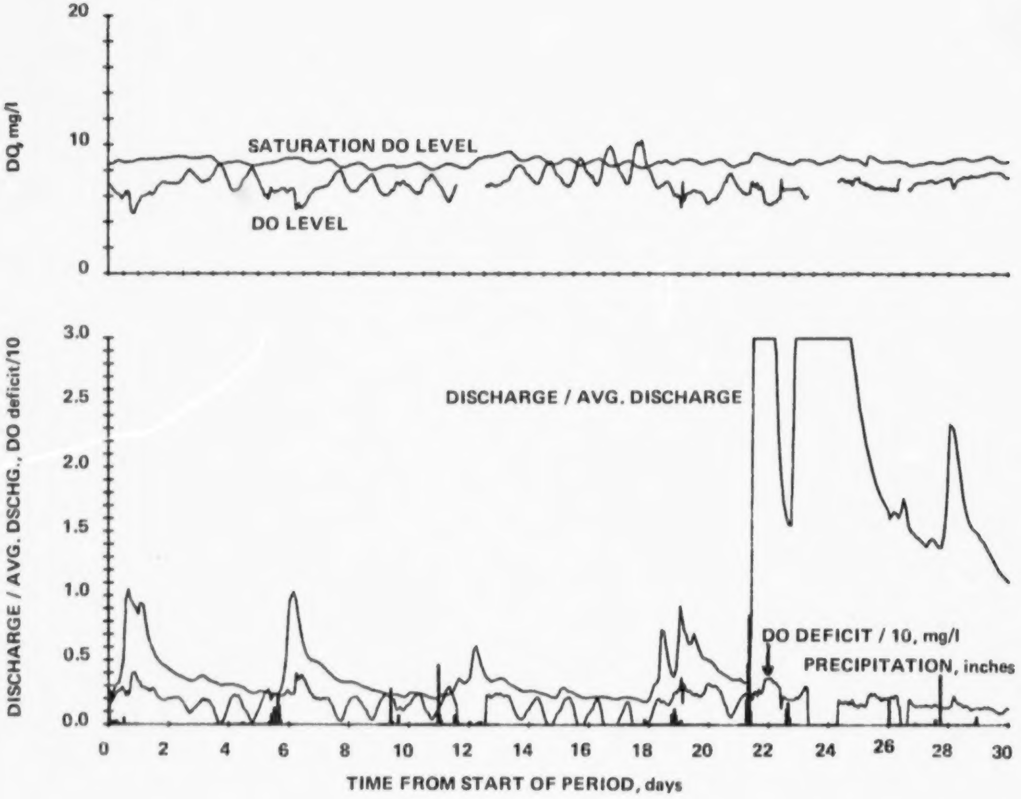

Figure D-15. Hourly data for Cuyahoga R. at Independence, OH. (6/19/76 to 7/18/76).

The hydraulics of the Akron sewer system are quite complex, but the reach from the Cuyahoga at Old Portage gage to the Independence gage would be good because the input and output D.O. levels are monitored. The Akron treatment plant lies between the two gages.

STATE: OHIO

Monitor Name: Cuyahoga River at Old Portage
USGS I.D.: 04 206 000 Latitude: 41 08 08 Longitude: 81 32 50

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Cleveland WB APT
Weather Bureau I.D.: 1657

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. with high flow never exceeded 47 percent. The probability of low D.O. or days with rain exceeded 60 percent in 1976 and averaged 57 percent for the period examined. Water quality is marginal at 60 to 75 percent of saturation.

Quality of Records: Monitor is visited once a month or more. Both flow and monitor records are very good with little missing data.

Discharge Characteristics: Average flow 400 cfs, range 25-8,000 cfs

Drainage Area at Monitor: 404 square miles

Urban Area(s) Contributing at Monitor: Akron, approx. population 690,000, including suburbs

Approximate Urban Area Contributing at Monitor: 50 square miles or 12 percent of total

Results of Streeter-Phelps Analysis: The analysis indicates that the monitor is too close to Akron to sense the maximum sag in a Streeter-Phelps sense. The Cuyahoga at Independence monitor is better situated. The analysis is illustrated in Figure D-14.

Hourly Data Analysis Results: The period examined is illustrated in Figure D-16. This is the same time period examined for the Cuyahoga at Independence monitor. A slight increase in the D.O. deficit and a definite dampening of the diurnal D.O. cycles can be seen for the first two flow events. The effect is not as pronounced as at Independence. Water quality is marginal, averaging 6 mg/l. It is difficult to conclude much from this hourly data. Examination of 1976 daily data indicates several places where D.O. levels well below 5 mg/l occur with increased flow.

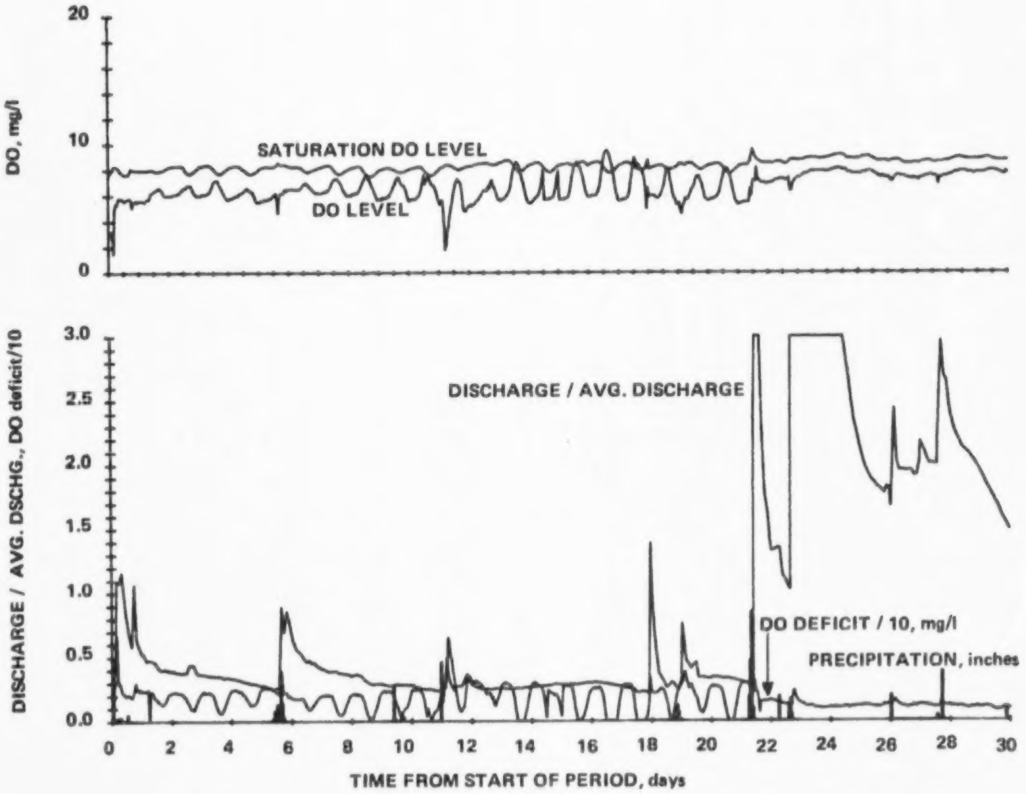

Figure D-16. Hourly data for Cuyahoga R. at Old Portage, OH. (6/19/76 to 7/18/76).

Conclusions and Comments: A problem can be identified here, but not as well as at Independence. It would be an interesting place to study in detail because sufficient evidence exists to show a correlation between both rain and flow and low D.O. The availability of monitor records here and at Independence would be very good for model calibration.

STATE: OHIO

Monitor Name: Grand River at Painsville
USGS I.D.: 04 212 200 Latitude: 41 44 09 Longitude: 81 15 59

Stream Gage Name: Grand River near Painsville
USGS I.D.: 04 212 100 Latitude: 41 43 08 Longitude 81 13 41

Rain Gage: Cleveland
Weather Bureau I.D.: 1657

Daily Data Analysis Results: Water years 1975 and 1976 were examined. The maximum probability of low D.O. with high flow was 45 percent. The probability of low D.O. on days with rain was 60 percent in 1975. D.O. levels fall in the 60 to 70 percent saturation range.

Quality of Records: The monitor is visited once a month or more. Flow records are good but the monitor record is very poor with nearly 1/3 of the year missing.

Discharge Characteristics: Average flow 1,000 cfs, range 50-13,000 cfs

Drainage Area at Monitor: 701 square miles

Urban Area(s) Contributing at Monitor: Painsville, approx. population 30,000

Approximate Urban Area Contributing at Monitor: 4 square miles or less than 1 percent of total

Results of Streeter-Phelps Analysis: This was not considered here. River empties into Lake Erie several miles downstream.

Hourly Data Analysis Results: The hourly data are illustrated in Figure D-17. There is some indication of increased deficit for the small flow event but the D.O. improves with the larger event. The evidence is inconclusive.

Conclusions and Comments: This site has occasional water quality problems with the D.O. dropping to less than 5 mg/l. There is no real evidence to connect this to direct urban runoff. There is no obvious correlation with flow and the rainfall correlation is suspect because of the distance (60 miles) to the rain gage from the monitor.

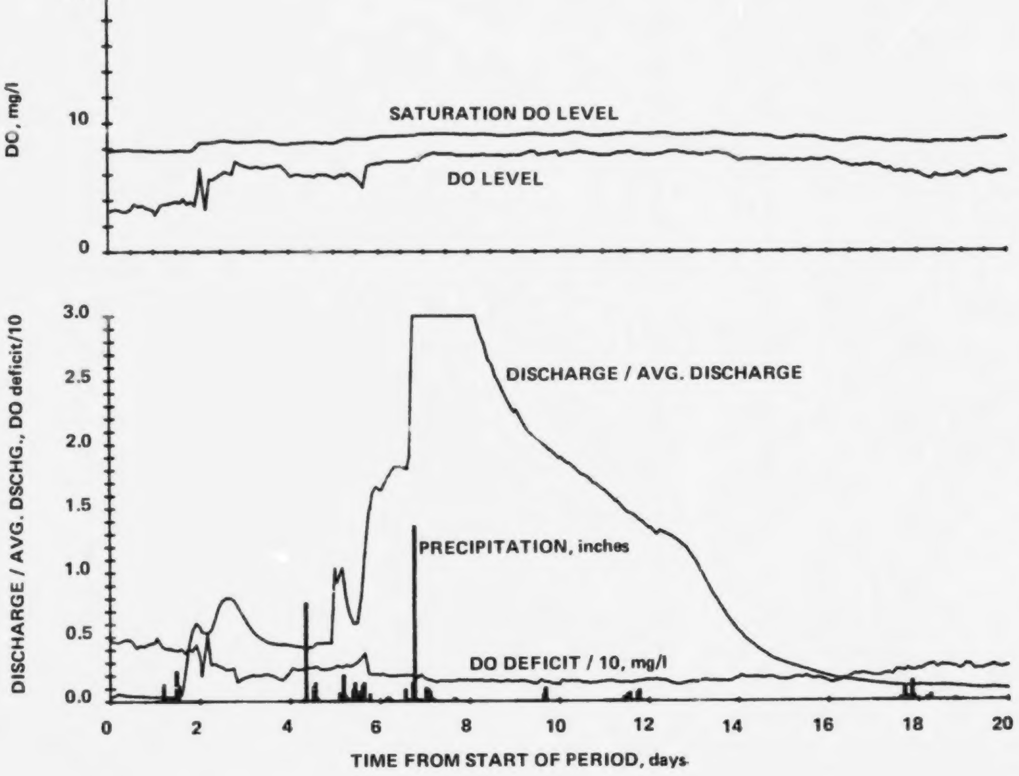

Figure D-17. Hourly data for Grand R. at Painesville, OH. (8/25/75 to 9/13/75).

STATE: OHIO

Monitor Name: Hocking River Below Athens
USGS I.D.: 03 159 510 Latitude: 39 19 39 Longitude: 82 00 18

Stream Gage Name: Hocking River at Athens
USGS. I.D.: 03 159 500 Latitude: 39 19 44 Longitude: 82 05 16

Rain Gage: Athens
Weather Bureau I.D.: 0279

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. and high flow reached 67 percent in 1976. The dissolved oxygen levels are generally high, averaging 65 to 86 percent of saturation.

Quality of Records: The monitor is visited once a month or more. Both flow and monitor records are good with little missing data.

Discharge Characteristics: Average flow approx. 1,000 cfs, range 25-30,000 cfs

Drainage Area at Monitor: 943 square miles

Urban Area(s) Contributing at Monitor: Athens, approx. population 15,000

Approximate Urban Area Contributing at Monitor: 2 square miles or less than 1 percent of total

Results of Streeter-Phelps Analysis: Analysis indicates that the monitor is too close to town. A location 15 to 20 miles downstream would have been better. Even storm flow seems incapable of doing much harm to water quality here. The analysis results are illustrated in Figure D-18.

Hourly Data Analysis Results: The period examined is illustrated in Figure D-19. It is highly inconclusive evidence of anything. The D.O. level decreases slightly as the flow events continue to occur, but that is all. D.O. levels are high, running quite near saturation. Some evidence of supersaturation is apparent for the first three days of the period examined.

Conclusions and Comments: Examination of the daily record indicates that the D.O. does drop below 5 mg/l in the summer, but no evidence is present in the hourly to say that it is an urban runoff problem. Possibly the level of sewage treatment is inadequate. There is little else shown on the map to suspect.

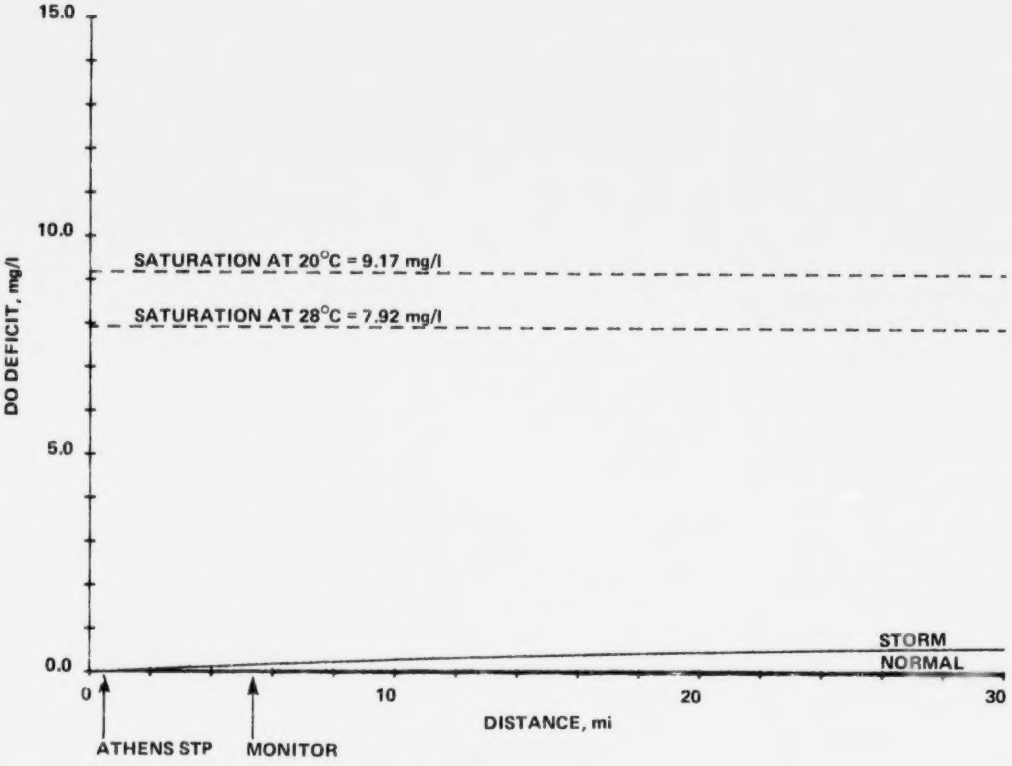

Figure D-18. Streeter-Phelps analysis results for Hocking R. below Athens, OH.

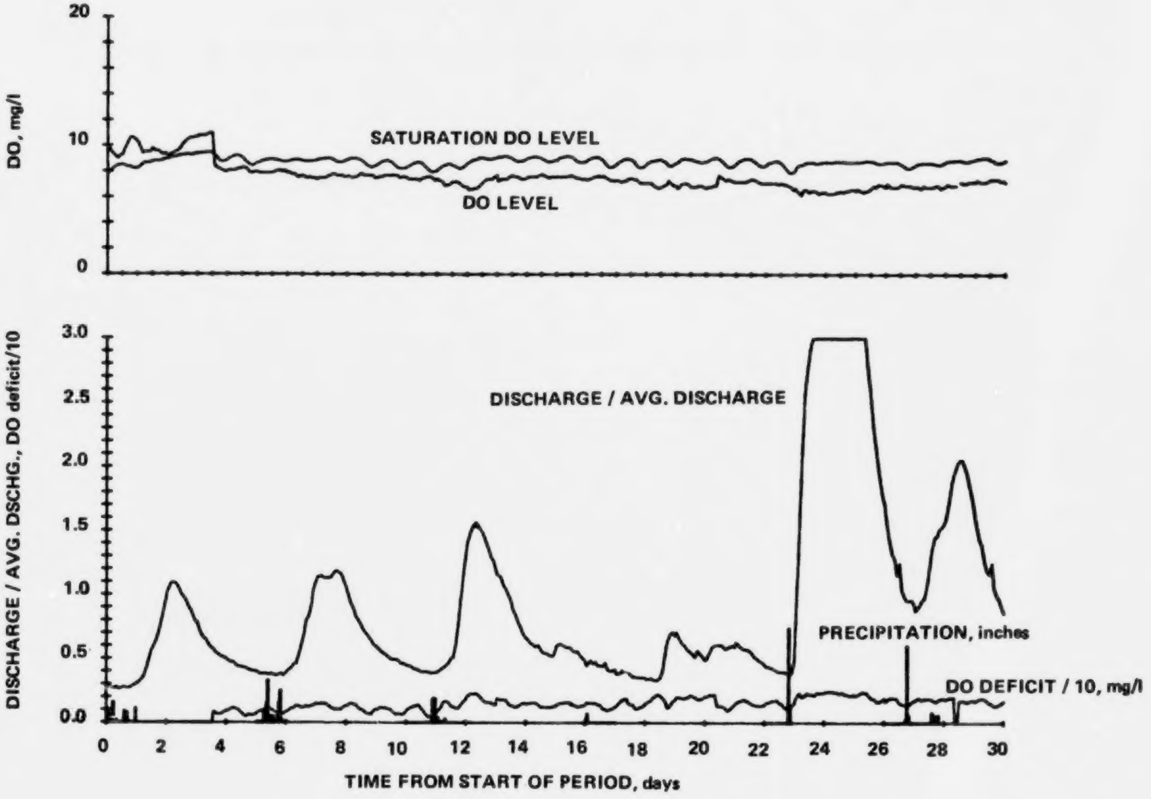

Figure D-19. Hourly data for Hocking R. at Athens, OH. (6/19/76 to 7/18/76).

STATE: OHIO

Monitor Name: Little Miami River at Miamiville
USGS I.D.: 03 245 300 Latitude: 39 12 38 Longitude: 84 17 33

Stream Gage Name: Little Miami River at Milford
USGS I.D.: 03 245 500 Latitude: 39 10 17 Longitude: 84 17 53

Rain Gage: Cincinnati ABBE OBS
Weather Bureau I.D.: 1561

Daily Analysis Results: Water years 1971 to 1974 were examined. The probability of low D.O. and high flow reached 67 percent in 1974 and 66 percent in 1973. The probability of low D.O. on days with rain never exceeded 60 percent. Water quality is generally good at the site with D.O. levels averaging 80-85 percent saturation.

Quality of Records: The monitor is visited once a month or more. Both flow and D.O. records are generally continuous.

Discharge Characteristics: Average flow 1,200 cfs, range 100-60,000 cfs

Drainage Area at Monitor: 1200 square miles

Urban Area(s) Contributing at Monitor: Suburbs of Cincinnati, population difficult to estimate

Approximate Urban Area Contributing at Monitor: unknown - probably less than 1 percent

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: The period of hourly data examined is illustrated in Figure D-20. There is clear evidence of an increased D.O. deficit at the time of the flow events shown. The dissolved oxygen level fell near the 5 mg/l level during the events.

Conclusions and Comments: There is clearly a correlation here, but the cause is not clear. The writers visited the site and it is not obviously urban. The monitor is near several small towns in the fringe suburbs of Cincinnati. There is a good deal of gravel mining and cement processing upstream. Deficit levels are not severe enough to warrant further study here.

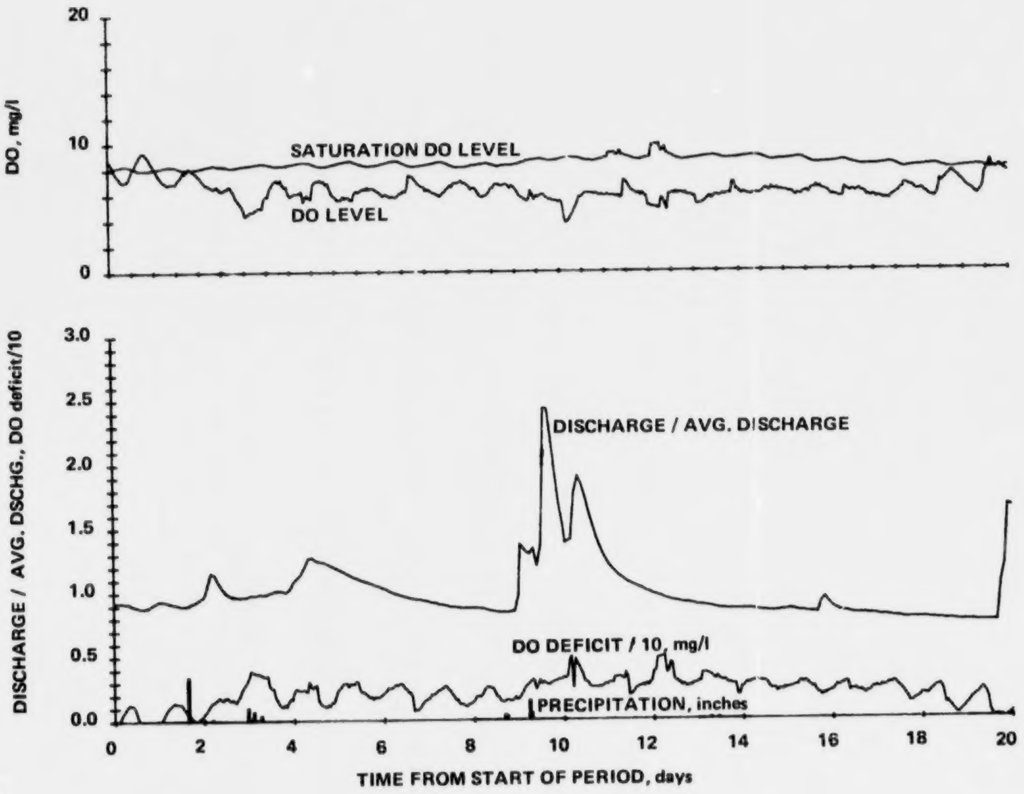

Figure D-20. Hourly data for L. Miami R. at Miamiville, OH. (8/1/73 to 8/30/73).

STATE: OHIO

Monitor Name: Little Miami River near Spring Valley
USGS I.D.: 03 242 050 Latitude: 39 35 00 Longitude: 84 01 49

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Dayton WB APT
Weather Bureau I.D.: 2075

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. with high flow reached 58 percent in 1972, 59 percent in 1976, and exceeded 60 percent in 1974 and 1975. The probability of low D.O. on days with rainfall exceeded 60 percent in 1974 and 1975. Dissolved oxygen levels ranged from 60 to 75 percent saturation.

Quality of Records: The monitor is visited once a month or more. The flow record is continuous. The monitor record is generally continuous with an occasional two to three weeks missing.

Discharge Characteristics: Average flow 386 cfs, range 23-18,400 cfs

Drainage Area at Monitor: 366 square miles

Urban Area(s) Contributing at Monitor: Dayton, Dayton suburbs, Xenia, approximate populations 60-70,000 and 25,000 respectively

Approximate Urban Area Contributing at Monitor: 11 to 13 square miles or 3 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: A clear correlation exists between the presence of storm event flow and a lowering of the dissolved oxygen level for the period examined. This is illustrated in Figure D-21. There is a fairly clear relationship between the rainfall events and small increases in the D.O. deficit. The D.O. level is driven close to the 5 mg/l level by the flow event.

Conclusions and Comments: Sutron contacted the cities of Dayton and Xenia concerning the correlation observed here. The Assistant City Manager at Xenia indicates that the discharge of raw sewage at times of high flow from the city of Spring Valley is probably the reason

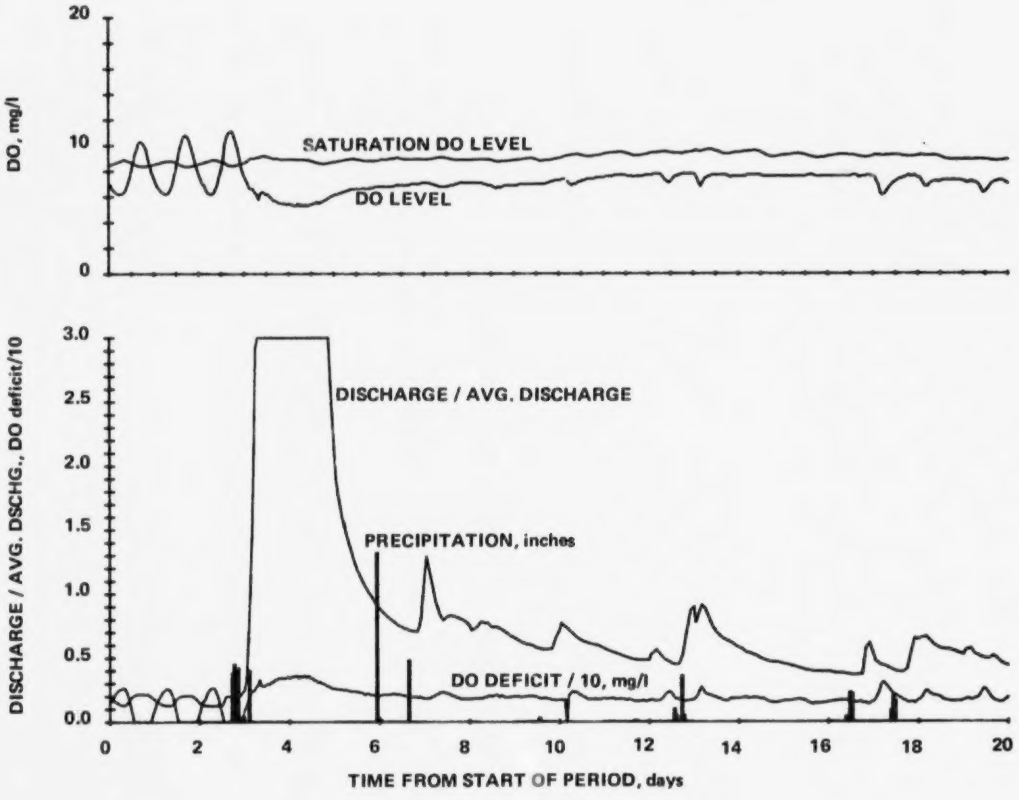

Figure D-21. Hourly data for L. Miami R. near Spring Valley, OH.
(7/1/75 to 7/20/65).

for poor water quality here. The correlation is unmistakeable here and a limited further investigation may be warranted.

STATE: OHIO

Monitor Name: Mad River near Dayton
USGS I.D.: 03 270 000 Latitude: 84 05 19 Longitude: 84 05 19

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Dayton WB APT
Weather Bureau I.D.: 2075

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. at times of high flow reached 56 percent in 1975 and exceeded 60 percent in 1972. The probability of low D.O. days with rainfall exceeded 60 percent all 5 years. Dissolved oxygen levels are generally in the 60 to 75 percent of saturation range.

Quality of Records: The monitor is visited once a month or more. Records are generally continuous for both flow and the monitor. Occasional periods of one to two weeks are missing.

Discharge Characteristics: Average flow 620 cfs, range 100-20,000 cfs

Drainage Area at Monitor: 635 square miles

Urban Area(s) Contributing at Monitor: Springfield, small portion of Dayton suburbs, Wright Patterson Air Force Base, approximate population 90-100,000

Approximate Urban Area Contributing at Monitor: 11-12 square miles or 2 percent of total

Results of Streeter-Phelps Analysis: Streeter-Phelps analysis indicates that a storm flow at Springfield could produce a deficit of 4-5 mg/l at the monitor. The monitor is probably 10 to 12 miles too far downstream to best sense effects from Springfield. The results are illustrated in Figure D-22.

Hourly Data Analysis Results: The hourly data examined are illustrated in Figure D-23. There is a fairly clear correlation between periods of high flow and periods when the D.O. deficit remains high. The minimum value at times of high flow is no worse than on normal days but no recovery to "better" conditions takes place. The correlation between the rainfall and flow events is fairly clear. D.O. levels fall to roughly 5-6 mg/l. While the correlation is clear, no real problem seems to exist here as far as standards go.

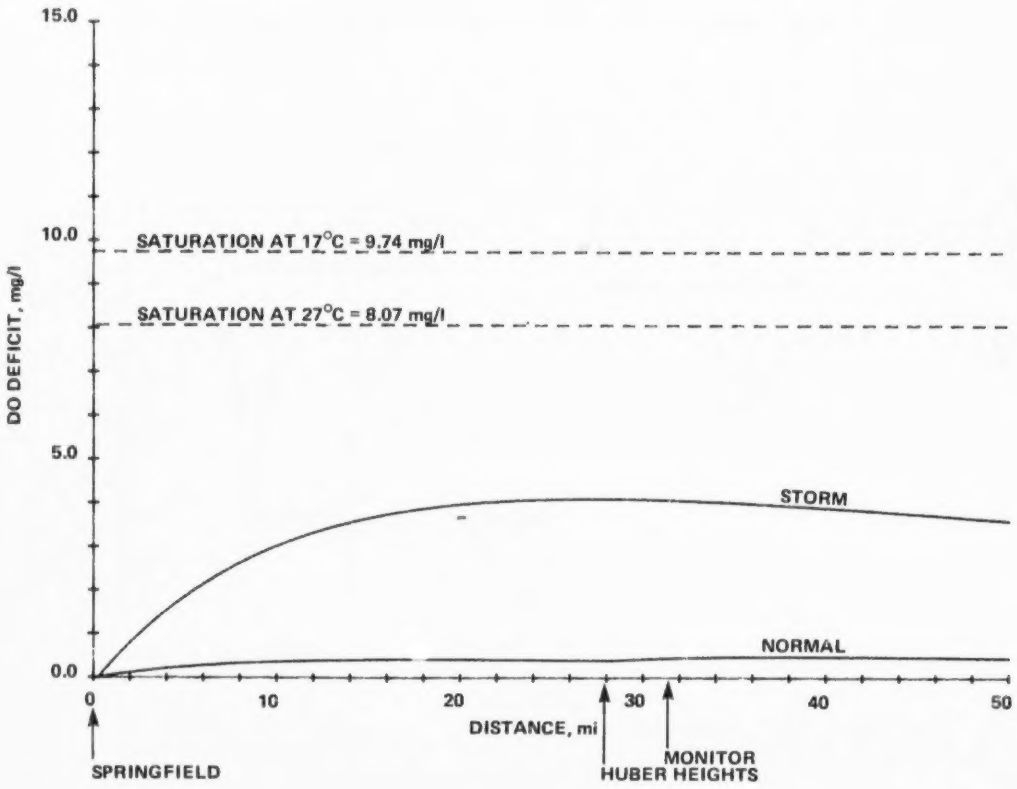

Figure D-22. Streeter-Phelps analysis results for Mad R. near Dayton, OH.

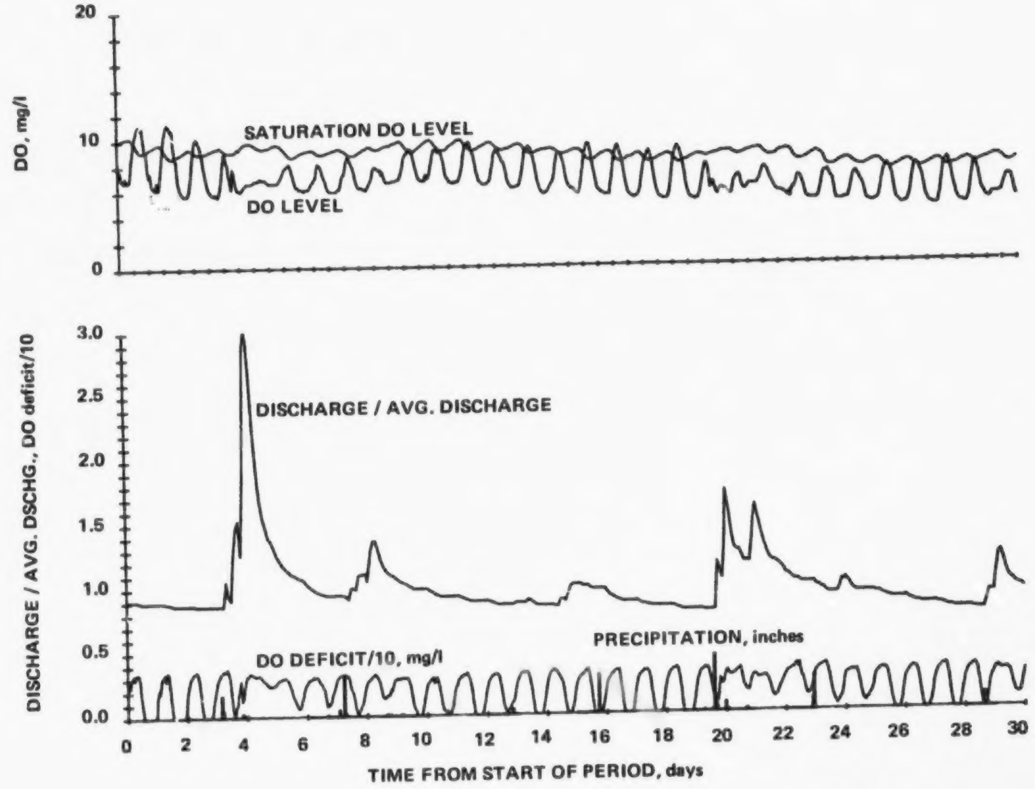

Figure D-23. Hourly data for Mad R. near Dayton, OH. (6/26/72 to 7/25/72).

Conclusions and Comments: This is a fairly good example of a correlation. It would require further study to determine if the monitor is actually located in a poor place and if the problem is worse upstream as indicated by Streeter-Phelps. The Streeter-Phelps results indicate that D.O. levels as low as 3.0 mg/l might be found.

STATE: OHIO

Monitor Name: Mahoning River at Ohio-Pennsylvania State Line
below Lowellville
USGS I.D.: 03 099 510 Latitude: 41 01 53 Longitude: 80 31 10

Stream Gage Name: Mahoning River at Lowellville
USGS I.D.: 03 099 500 Latitude: 41 02 12 Longitude: 80 32 11

Rain Gage: Youngstown
Weather Bureau I.D.: 9406

Daily Data Analysis Results: Water years 1973-1976 were examined. The probability of low D.O. at times of high flow days with rainfall reached 60 percent in 1976. Water quality is fairly poor with D.O. levels averaging from 45 to 55 percent saturation. The 1976 daily data are illustrated in Figure D-24. There are clearly identifiable periods when flow events coincide with periods of near zero dissolved oxygen. The rainfall correlation is also clear.

Quality of Records: The monitor is visited once a month or more. Both flow and monitor records are excellent with only isolated periods of 3-5 days missing.

Discharge Characteristics: Average flow 1400 cfs, range 700-7,000 cfs

Drainage Area at Monitor: 1073 square miles

Urban Area(s) Contributing at Monitor: Niles, Girard, Youngstown, approx. population 550,000, including metropolitan area.

Approximate Urban Area Contributing at Monitor: 25 square miles or 2 percent of total

Results of Streeter-Phelps Analysis: The results of the analysis are shown in Figure D-25. Storm flow from Youngstown is theoretically capable of driving the D.O. to zero. The monitor should ideally be 10 to 15 miles further downstream to sense this. It seems to be getting the full effect where it's at now, however.

Hourly Data Analysis Results: Hourly data could not be obtained at this site. The daily analysis clearly indicates the correlation between both rainfall, flow and low D.O.

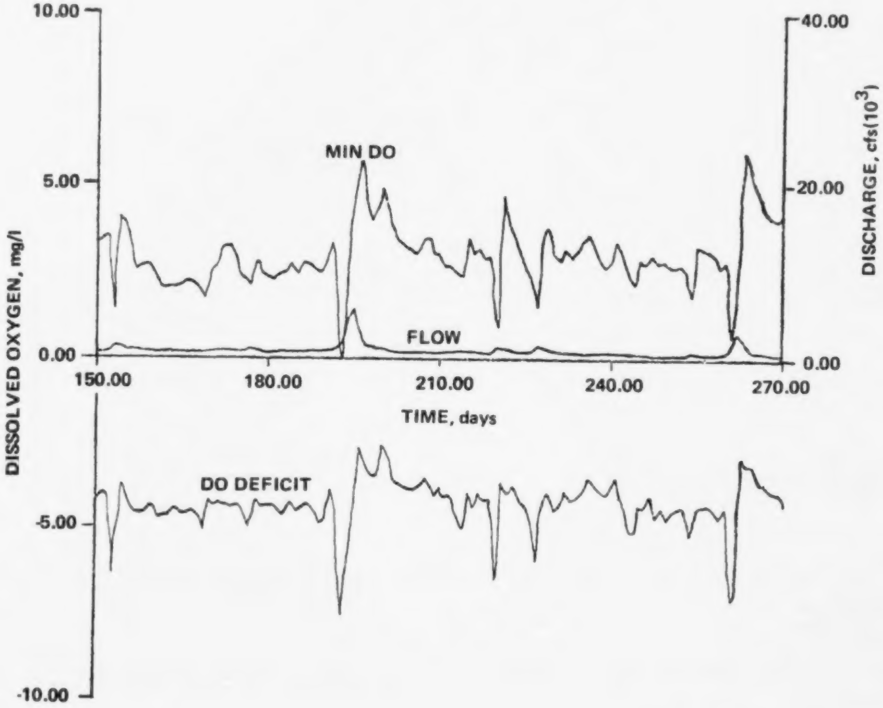

Figure D-24. Daily DO and flow for Mahoning R. at OH.-PA. state line below Lowellville, OH.

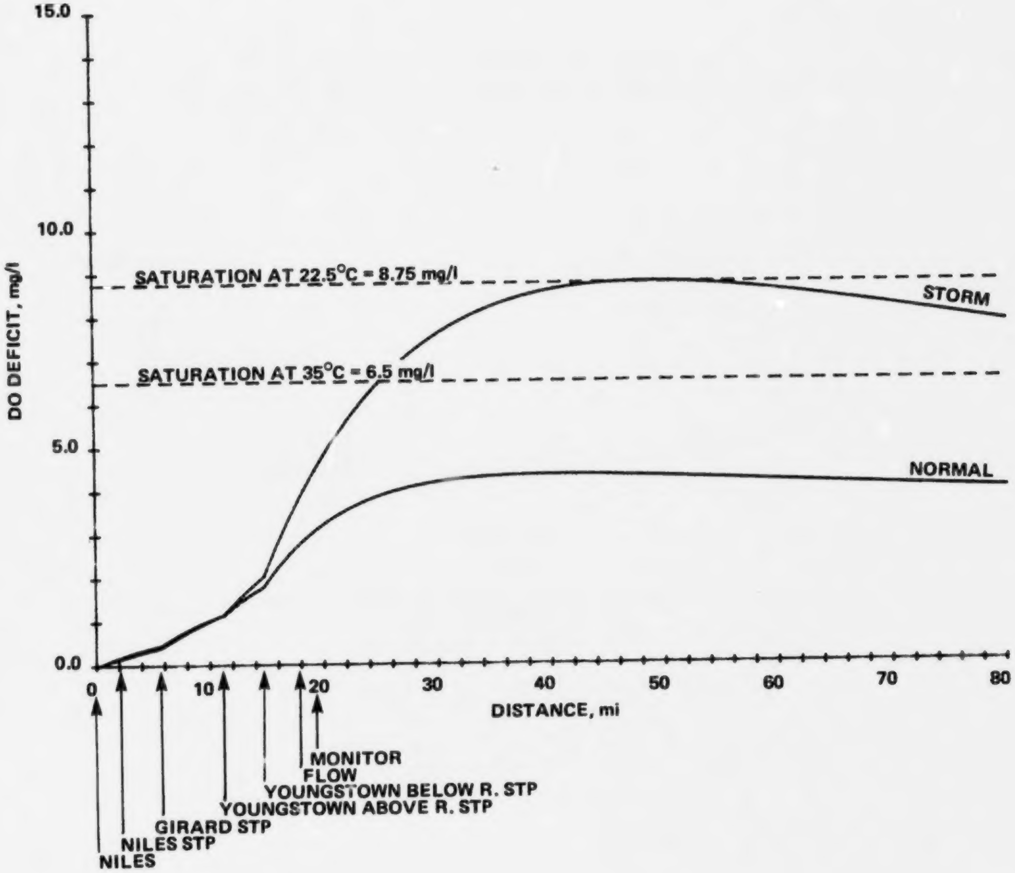

Figure D-25. Streeter-Phelps analysis results for Mahoning R. at OH.-PA. state line near Lowellville, OH.

Conclusions and Comments: Youngstown is very heavily industrialized. The entire river valley is a mess of rail yards and steel plants. The entire urban area drains into the river. Sutron contacted the Youngstown treatment facility and learned that no facilities above primary level exist in the Mahoning Valley. A secondary treatment facility for Youngstown has reached final design stages.

STATE: OHIO

Monitor Name: Maumee River at Defiance
USGS I.D.: 04 184 100 Latitude: 41 16 43 Longitude: 84 23 07

Stream Gage Name: Maumee River at Antwerp
USGS I.D.: 04 183 500 Latitude: 41 11 56 Longitude: 84 44 40

Rain Gage: Defiance
Weather Bureau I.D.: 2098

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. at times of high flow exceeded 60 percent in 1973 and 1975. The D.O. levels are generally in the 60 to 70 percent of saturation range.

Quality of Records: The monitor is visited once a month or more. The record quality, however, is poor. One to two months of record are missing each year. Much of the record missing is in the summer when it would have been of most interest.

Discharge Characteristics: Average flow 2680 cfs, range 26-26,200 cfs

Drainage Area at Monitor: 2300 square miles

Urban Area(s) Contributing at Monitor: Fort Wayne, Indiana (none of Defiance), population 182,000

Approximate Urban Area Contributing at Monitor: 25 square miles or 1 percent of total

Results of Streeter-Phelps Analysis: The Streeter-Phelps technique was used to determine if the problem observed could originate at Fort Wayne, Indiana. This was done because the monitor is upstream of all of Defiance. The results, illustrated in Figure D-26, indicate that storm flow from Fort Wayne could cause a 4-5 mg/l deficit (2-3 mg/l absolute DO level) at Defiance. The monitor would have been better located at Antwerp, Indiana, to sense the maximum deficit.

Hourly Data Analysis Results: Hourly data were not examined at this site because of the large distance between the monitor and flow gages (20+ miles).

Conclusions and Comments: It seems quite probable that 5.0 mg/l standard violations would be detected by a properly placed monitor. EPA standards violations might also be found. The daily data are of poor quality, however, and the monitor is not in the best location. The reach from Fort Wayne to Antwerp would definitely be worth investigating.

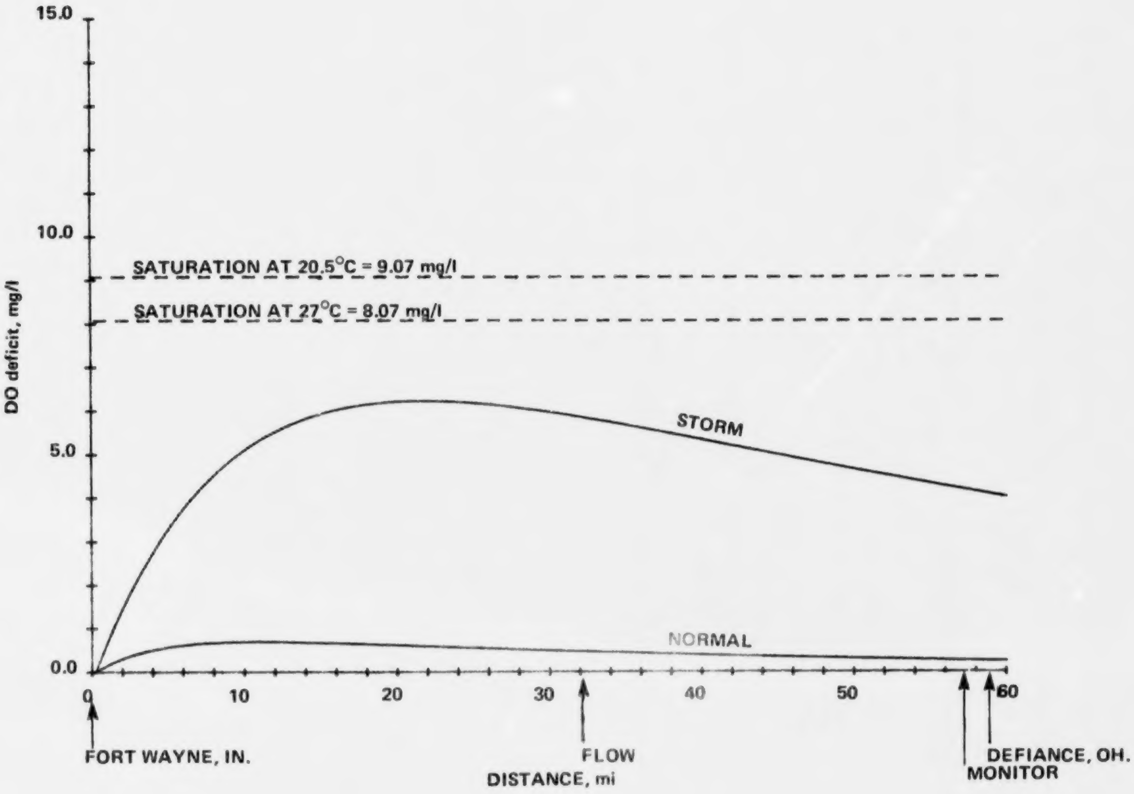

Figure D-26. Streeter-Phelps analysis results for Maumee R. at Defiance, OH.

STATE: OHIO

Monitor Name: Portage River at Railroad Bridge at Woodville
USGS I.D.: 04 195 600 Latitude: 41 26 58 Longitude: 83 21 29

Stream Gage Name: Portage River at Woodville
USGS I.D.: 04 195 500 Latitude: 41 26 58 Longitude: 83 21 41

Rain Gage: Freemont
Weather Bureau I.D.: 2974

Daily Data Analysis Results: Water years 1971-75 were examined. The probability of low D.O. with high flow exceeded 60 percent in 1973 and reached 68 percent in 1975. Dissolved oxygen levels generally fall in the 50 to 70 percent saturation range.

Quality of Records: The monitor is visited once a month or more. The flow record is continuous. The monitor record usually contains periods of from two weeks to a month or more missing each year.

Discharge Characteristics: Average flow 300 cfs, range 0-17,000 cfs

Drainage Area at Monitor: 428 square miles

Urban Area(s) Contributing at Monitor: Bowling Green, Portage, approximate population 22,000 and less than 5,000 respectively

Approximate Urban Area Contributing at Monitor: 3 square miles or 1 percent of total

Results of Streeter-Phelps Analysis: Results of the analysis are shown in Figure D-27. They indicate that storm flow at Bowling Green might create a D.O. deficit of 3.5 to 4 mg/l at Woodville. The monitor location is too far downstream for ideal study of a problem at Bowling Green.

Hourly Data Analysis Results: The period examined is illustrated in Figure D-28. There is a clear tendency for the D.O. deficit to increase and hold steady at times of high flow. The correlation of the flow events with rainfall is also clear. D.O. levels fall to roughly 6 mg/l at times of high flow.

Conclusions and Comments: There is clear evidence of a correlation here. Water quality in the river may be worse than indicated because of poor monitor location. The urban area involved is relatively small, but would probably be worth investigating.

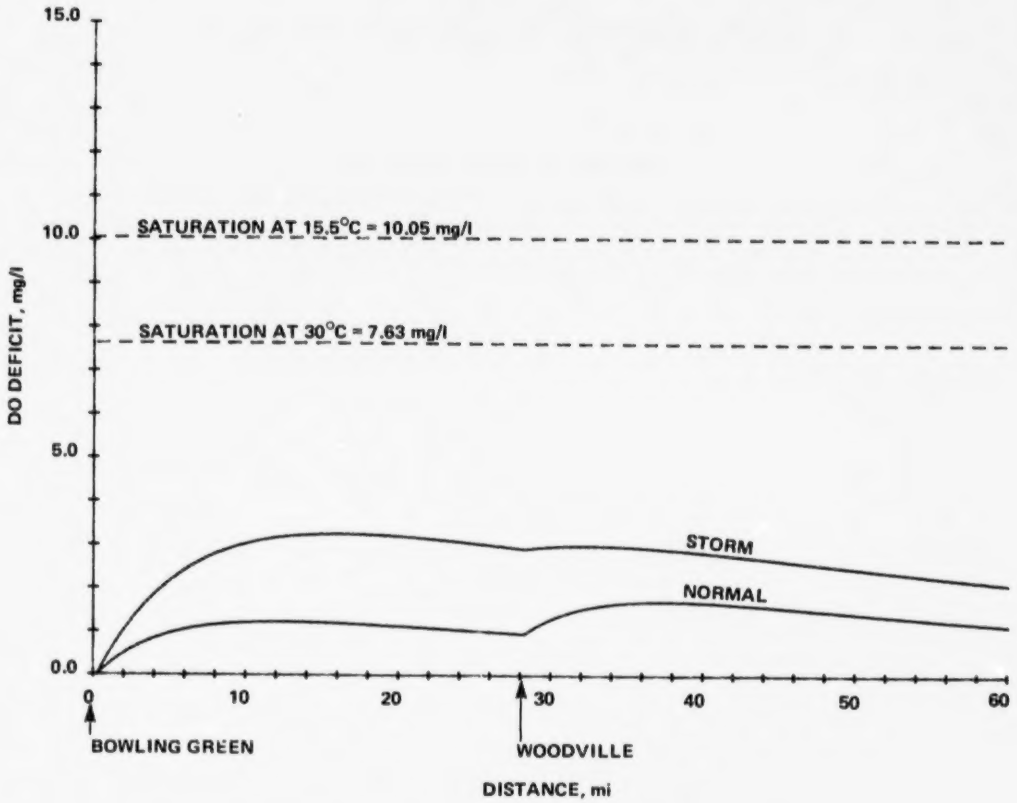

Figure D-27. Streeter-Phelps analysis results for Portage R. at Railroad Bridge at Woodville, OH.

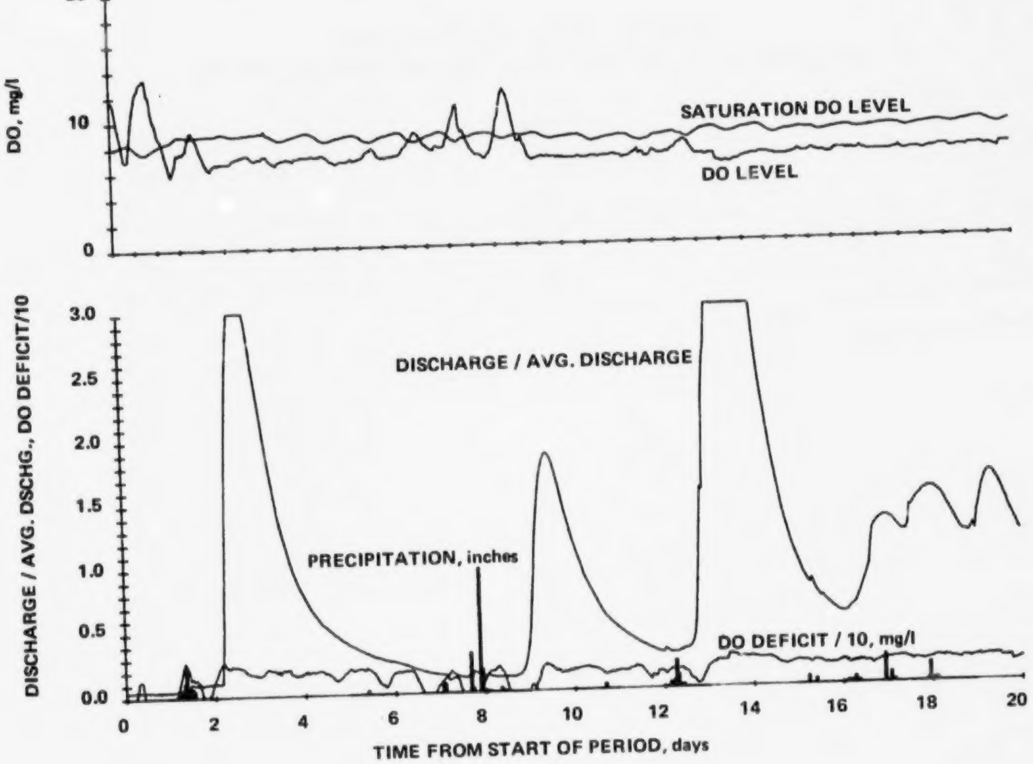

Figure D-28. Hourly data for Portage R. at Woodville, OH.
(8/14/75 to 9/2/75).

STATE: OHIO

Monitor Name: Sandusky River near Upper Sandusky
USGS I.D.: 04 196 500 Latitude: 40 51 02 Longitude: 83 15 23

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Upper Sandusky
Weather Bureau I.D.: 8534

Daily Data Analysis Results: Water Years 1972-76 were examined. The probability of low D.O. with high flow reached 60 percent in 1973 and exceeded 60 percent in 1976. The probability of low D.O. on days with rainfall exceeded 60 percent in 1974, 75 and 76. D.O. levels were generally in the 70-75 percent of saturation range. Periods when low D.O. occurs at times of both flow and rainfall can be clearly identified on the daily plots.

Quality of Records: The monitor is visited once a month or more. The flow record is continuous. The monitor record has minor interruptions occasionally but these are infrequent and of short duration.

Discharge Characteristics: Average flow 250 cfs, range 10-10,000 cfs

Drainage Area at Monitor: 298 square miles

Urban Area(s) Contributing at Monitor: Bucyrus, Upper Sandusky, approximate population 13,000 and 7500 respectively

Approximate Urban Area Contributing at Monitor: 3 square miles or 1 percent of total

Results of Streeter-Phelps Analysis: The results of the analysis are shown in Figure D-29. The storm flow from Bucyrus could conceivably cause a 3-4 mg/l deficit at Upper Sandusky. The monitor is not in a good position to sense the effect of either town.

Hourly Data Analysis Results: The period analyzed is illustrated in Figure D-30. There is clear evidence that a rainfall event followed by a flow increase is accompanied by an increase in D.O. deficit. The period examined contained one severe deficit where the D.O. level fell to less than 1 mg/l.

Conclusions and Comments: There is clear evidence of a problem here. The exact cause is not obvious, although it probably originates at Bucyrus. The monitor is rather poorly located

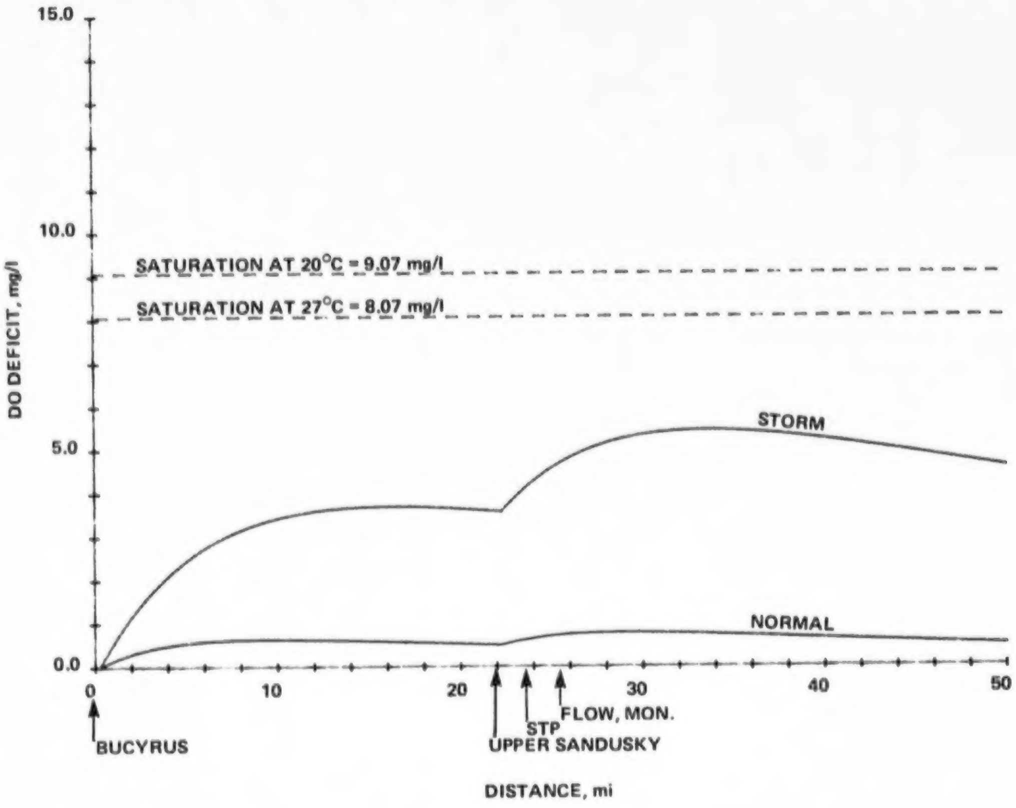

Figure D-29. Streeter-Phelps analysis for Sandusky R. near Upper Sandusky, OH.

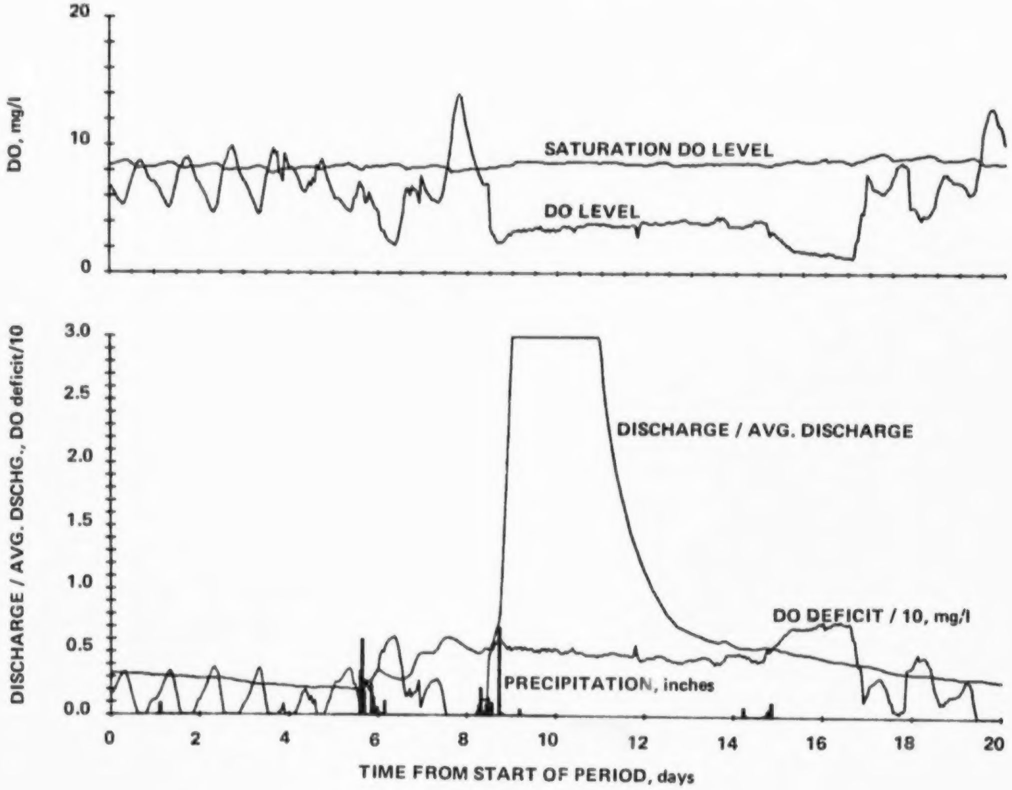

Figure D-30. Hourly data for Sandusky R. near Upper Sandusky, OH. (8/6/73 to 8/25/73).

in a Streeter-Phelps sense but still picks up the problem. This site would also be worth examining more closely. In an independent study, Ohio State University indicated that poor treatment facilities at Bucyrus may cause problems in the Sandusky.

STATE: OHIO

Monitor Name: Scioto River at Chillicothe
USGS I.D.: 03 231 500 Latitude: 39 20 29 Longitude: 82 58 16

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Chillicothe-Mound City
Weather Bureau I.D.: 1528

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. with high flow exceeded 50 percent all five years and exceeded 60 percent in 1972. The probability of low D.O. or days with rainfall exceeded 60 percent in 1976. D.O. levels are generally in the 40 to 60 percent of saturation range. Periods of low D.O. which coincide with flow and rainfall events can be clearly identified on the daily data plots.

Quality of Records: The monitor is visited once a month or more. The flow record is continuous and the monitor record is very good. Only isolated periods of a few days are missing.

Discharge Characteristics: Average flow 35,000 cfs, range 500-50,000 cfs

Drainage Area at Monitor: 3850 square miles

Urban Area(s) Contributing at Monitor: Columbus, approximate population 1,069,000

Approximate Urban Area Contributing at Monitor: 22 square miles or 1 percent of total

Results of Streeter-Phelps Analysis: The results of the analysis are shown in Figure D-31. It is theoretically possible for storm flow from Columbus to create a 3-4 mg/l deficit at Chillicothe. The monitor is poorly located. It would probably see nearly twice the deficit if it were at Circleville, halfway between Columbus and Chillicothe.

Hourly Data Analysis Results: The period examined is illustrated in Figure D-32. There is clear evidence of a correlation between both rainfall and flow and increased D.O. deficit. In one storm event, the D.O. drops very near zero. This violates the EPA suggested 2.0 mg/l for 4.0 hours standard.

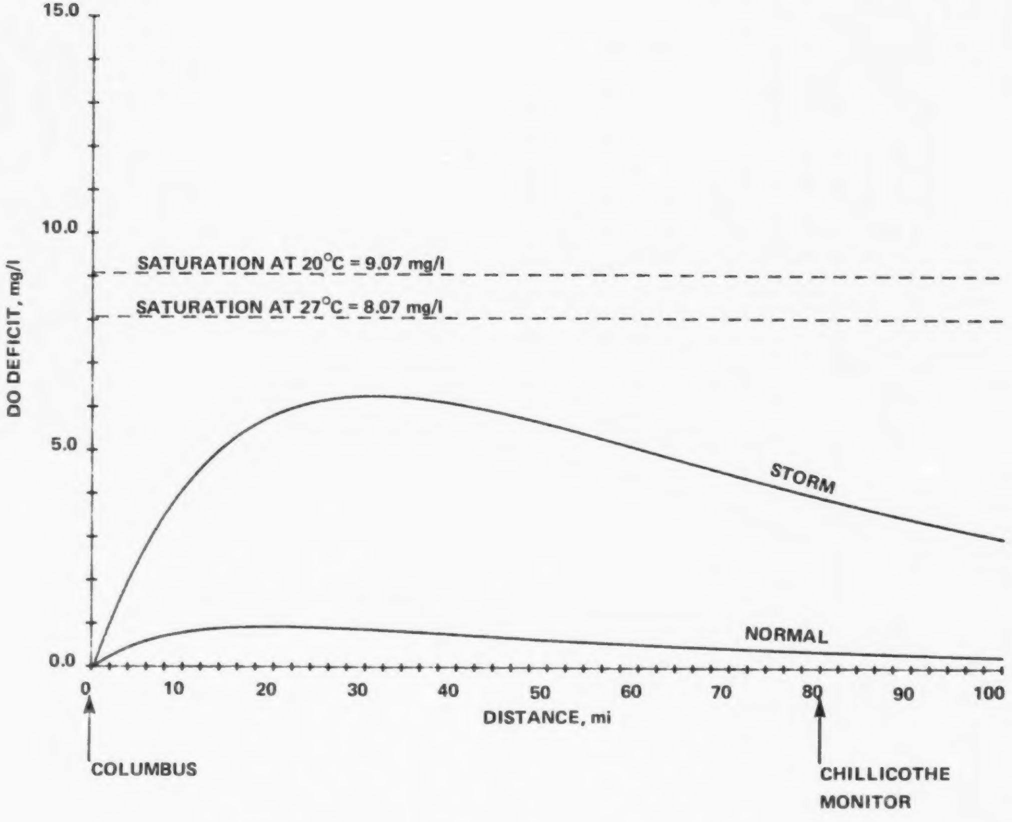

Figure D-31. Streeter-Phelps analysis for Scioto R. at Chillicothe, OH.

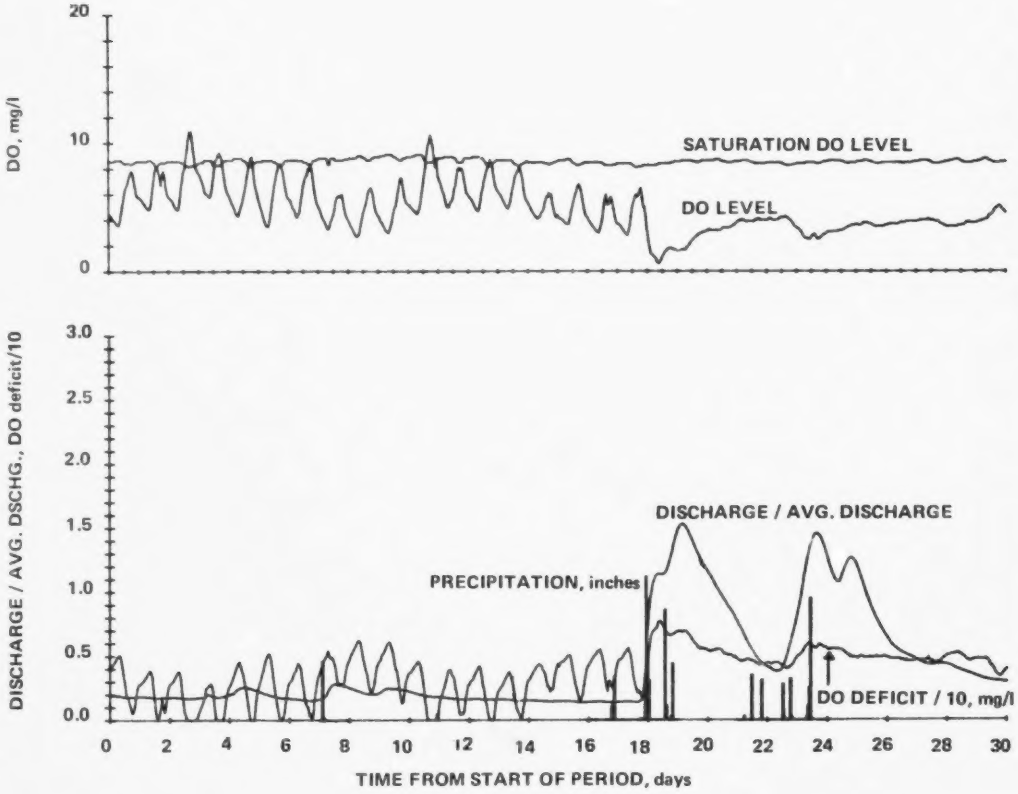

Figure D-32. Hourly data for Scioto R. at Chillicothe, OH. (8/1/72 to 8/30/72).

Conclusions and Comments: This is a good example of a site with a definite storm runoff related problem. It would definitely merit further study. One Sutron engineer worked with USGS in Columbus and is familiar with the Chillicothe monitor. He states that the diurnal oxygen variations are due to heavy algal growth in the channel. He also indicates that Columbus often flushes the trickling filters at the treatment plant during storm flows. Conversations with Columbus treatment facility operators indicate that storm flow bypassing does occur.

STATE: OREGON

Monitor Name: South Umpqua River near Roseburg
USGS I.D.: 14 312 260 Latitude: 43 13 20 Longitude: 123 24 45

Stream Gage Name: South Umpqua River near Brockway
USGS I.D.: 14 312 000 Latitude: 43 08 00 Longitude: 123 23 50

Rain Gage: Roseburg KQEN
Weather Bureau I.D.: 7331

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. with high flow reached 63 percent in 1976 and reached 57 and 56 percent in 1972 and 1973 respectively. The probability of low D.O. on days with rainfall never exceeded 50 percent. D.O. levels are generally high, averaging 80 to 87 percent saturation.

Quality of Records: The monitor is visited once a month or more. The flow and monitor records are both intermittent in the winter but are generally good.

Discharge Characteristics: Average flow 3,000 cfs, range 50 to 40,000 cfs

Drainage Area at Monitor: 1800 square miles

Urban Area(s) Contributing at Monitor: Winston, Roseburg, approximate combined population of 65,000 or more

Approximate Urban Area Contributing at Monitor: 9 square miles or 1 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: The period examined is illustrated in Figure D-33. There is clear evidence of an increased D.O. deficit accompanying an increase in flow. There is no real problem in a quality sense, as the D.O. remains above 8 mg/l at all times.

Conclusions and Comments: There is no doubt that something happens here. Periods of low D.O. at times of high flow can be clearly identified on the daily data plots. Based on other sites, the monitor would probably see a greater deficit were it located 20 miles further downstream. The low magnitude of the deficits do not appear to merit further study.

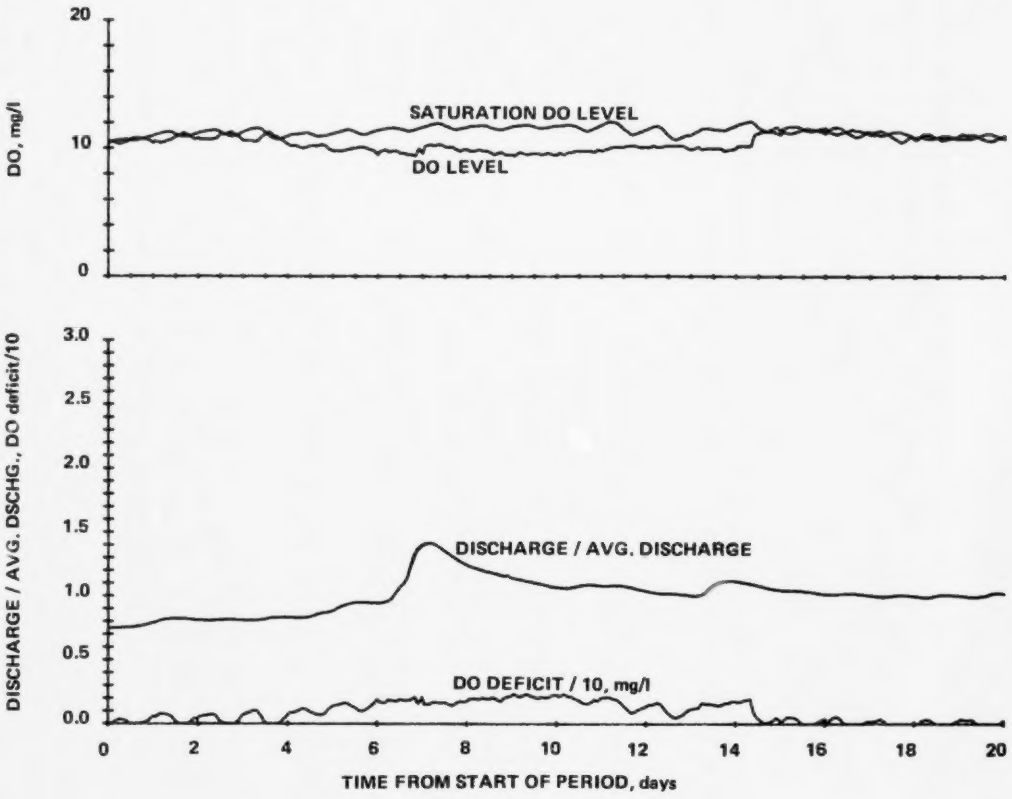

Figure D-33. Hourly data for South Umpqua R. near Brockway, OR.
(3/1/76 to 4/6/76)

STATE: PENNSYLVANIA

Monitor Name: Delaware River at Bristol
USGS I.D.: 01 464 600 Latitude: 40 05 55 Longitude: 74 51 58

Stream Gage Name: Delaware River at Trenton, New Jersey
USGS I.D.: 01 463 500 Latitude: 40 13 18 Longitude: 74 46 42

Rain Gage: Trenton
Weather Bureau I.D.: 8883

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. at times of high flow exceeded 50 percent all years. It reached 71 percent in 1975. Average D.O. levels ranged from 65 to 85 percent of saturation.

Quality of Records: The monitor is visited once a month or more. Records in the summer for the monitor are very bad with as much as two months missing. The flow record is continuous.

Discharge Characteristics: Average flow 12,000 cfs, range 200-32,500 cfs

Drainage Area at Monitor: 7163 square miles

Urban Area(s) Contributing at Monitor: Trenton, Levitown, Bristol, Bordentown, PA, and suburbs, population greater than 1/2 million

Approximate Urban Area Contributing at Monitor: 65 square miles or 1 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site.

Hourly Data Analysis Results: Hourly flow data were not available. The Trenton daily flows are plotted with the hourly D.O. and D.O. saturation data in Figure D-34. There is clearly an increase in D.O. deficit with increased flow. There is no real water quality problem, however, as the D.O. never falls below 8 mg/l.

Conclusions and Comments: The Trenton area forms the upstream end of a large urban megalopolis. Water quality deteriorates steadily from here to Philadelphia and below. The problem here is not bad enough to warrant further study.

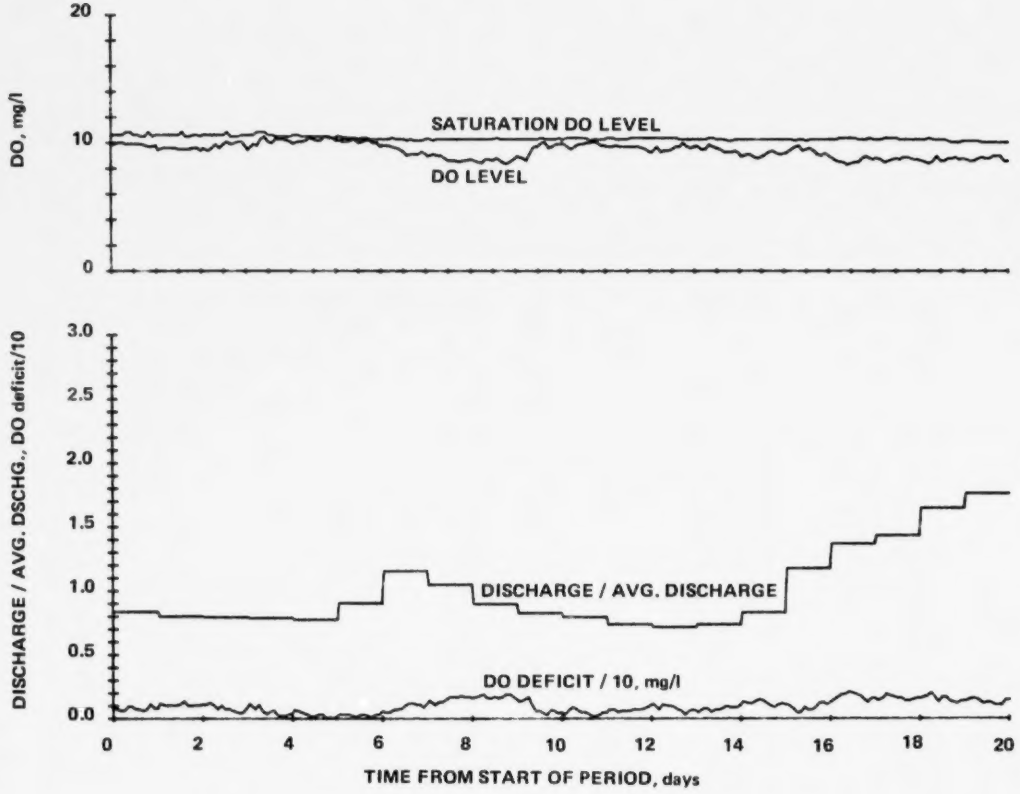

Figure D-34. Hourly data for Delaware R. at Bristol, PA.
(4/20/75 to 5/9/75)

STATE: PENNSYLVANIA

Monitor Name: Delaware River at Chester
USGS I.D.: 01 464 600 Latitude: 40 05 55 Longitude: 74 51 58

Stream Gage Name: Delaware River at Trenton, New Jersey
USGS I.D.: 01 463 500 Latitude: 40 13 18 Longitude: 74 46 42

Rain Gage: Philadelphia WB APT
Weather Bureau I.D.: 6889

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. with high flow exceeded 50 percent in 1973, 1974, and 1976, reaching a peak of 67 percent in 1973. D.O. levels average 65 to 75 percent of saturation.

Quality of Records: The monitor is visited once a month or more. Flow records are continuous. Monitor records are highly intermittent with roughly 1/3 of each month missing.

Discharge Characteristics: Average flow 12,000 cfs, range 1200-32,500 cfs

Drainage Area at Monitor: 10,300 square miles

Urban Area(s) Contributing at Monitor: Trenton, New Jersey, Philadelphia metropolitan area

Approximate Urban Area Contributing at Monitor: Greater than 100 square miles but less than 2 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site

Hourly Data Analysis Results: Hourly flow data were not available here. The hourly D.O. and D.O. saturation values are plotted with the Trenton, New Jersey, daily flows in Figure D-35. The D.O. level drops to less than 5 mg/l as the flow increases for the period examined. The relationship is not as pronounced as at other sites.

Conclusions and Comments: There is evidence of a correlation here. The fact that the D.O. can be driven down 4 mg/l by a drainage area which represents less than 2 percent of the total speaks for the potency of the runoff here. This is a very large river and the changes are much slower in a time sense than at other locations. This is probably too large and complex a site to study effectively at reasonable cost.

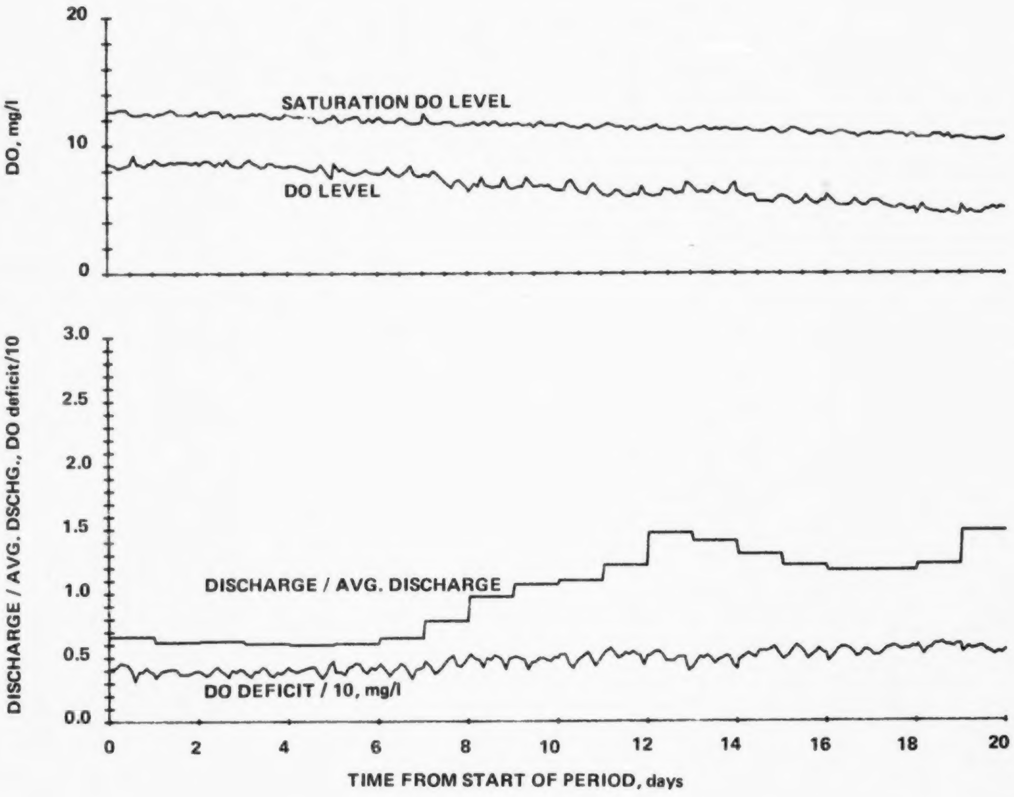

Figure D-35. Hourly data for Delaware R. at Chester, PA.
(2/26/73 to 3/17/73).

STATE: PENNSYLVANIA

Monitor Name: Lehigh River at Easton
USGS I.D.: 01 454 720 Latitude: 40 41 12 Longitude: 75 12 32

Stream Gage Name: Lehigh River at Glendon
USGS I.D.: 01 454 700 Latitude: 40 40 09 Longitude: 75 14 12

Rain Gage: Allentown WB APT
Weather Bureau I.D.: 0106

Daily Data Analysis Results: Water years 1972-1976 were examined. The probability of low D.O. with high flow reached 53 percent in 1972 but averaged 35 to 40 percent. The probability of low D.O. on days with rainfall exceeded 60 percent every year but 1974. That year it was 57 percent. D.O. levels in general are good, averaging 75 to 85 percent saturation. Periods of low D.O. at times of rianfall are discernable on the daily data plots.

Quality of Records: The monitor is visited once a month or more. Flow records are continuous. The monitor record exhibits intermittent missing periods of a week or less.

Discharge Characteristics: Average flow 3,000 cfs, range 1500-16,000 cfs

Drainage Area at Monitor: 1360 square miles

Urban Area(s) Contributing at Monitor: Allentown, Bethlehem, population approximately 610,000 and 71,500 respectively.

Approximate Urban Area Contributing at Monitor: 25 square miles or 2 percent of total

Results of Streeter-Phelps Analysis: The results of the analysis are shown in Figure D-36. Theoretically, storm flow from Allentown-Bethlehem could produce a deficit of 3-4 mg/l at Easton. The monitor could not be located at the sag point under any circumstances because the Lehigh joins the Delaware at Easton.

Hourly Data Analysis Records: The period examined is illustrated in Figure D-37. The results do not clearly show anything. The D.O. deficit appears to reach a maximum between the first and second rainfall events. As the flow increases, the D.O. level improves, nearly reaching saturation at one point. This type of behavior can also be seen on the daily plots. The deficit nears the 5 mg/l level at its worst.

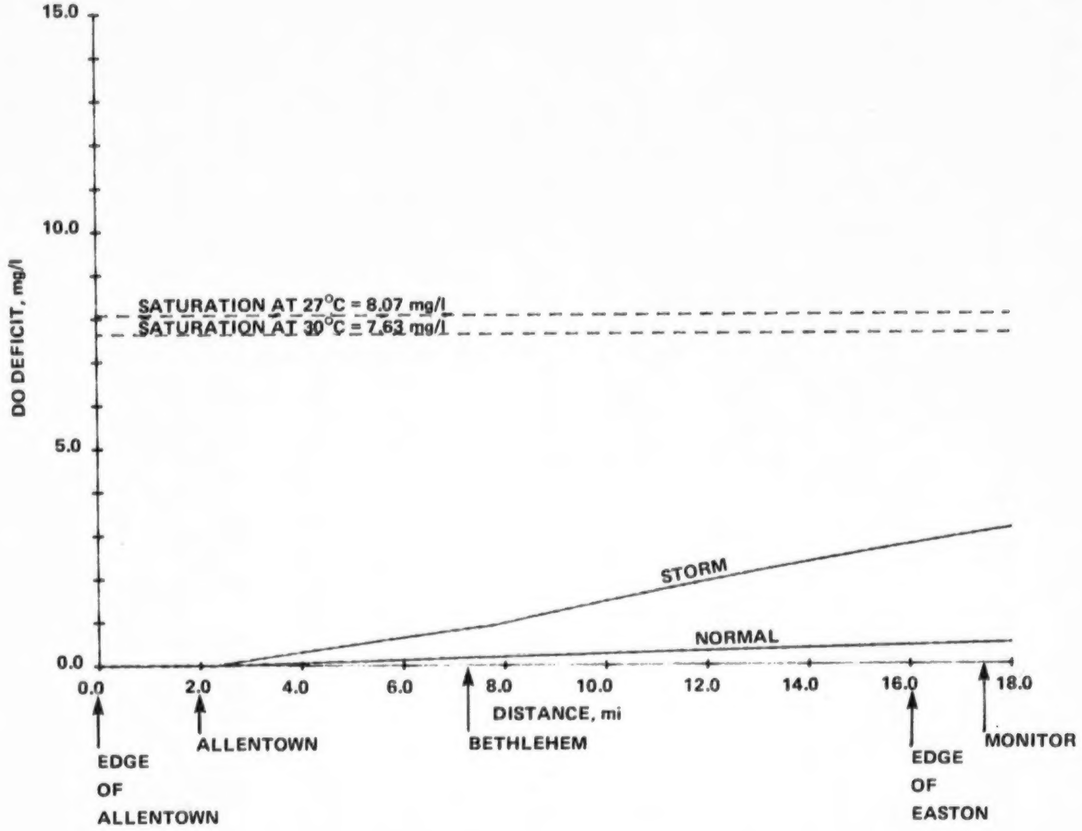

Figure D-36. Streeter-Phelps analysis for Lehigh R. at Easton, PA.

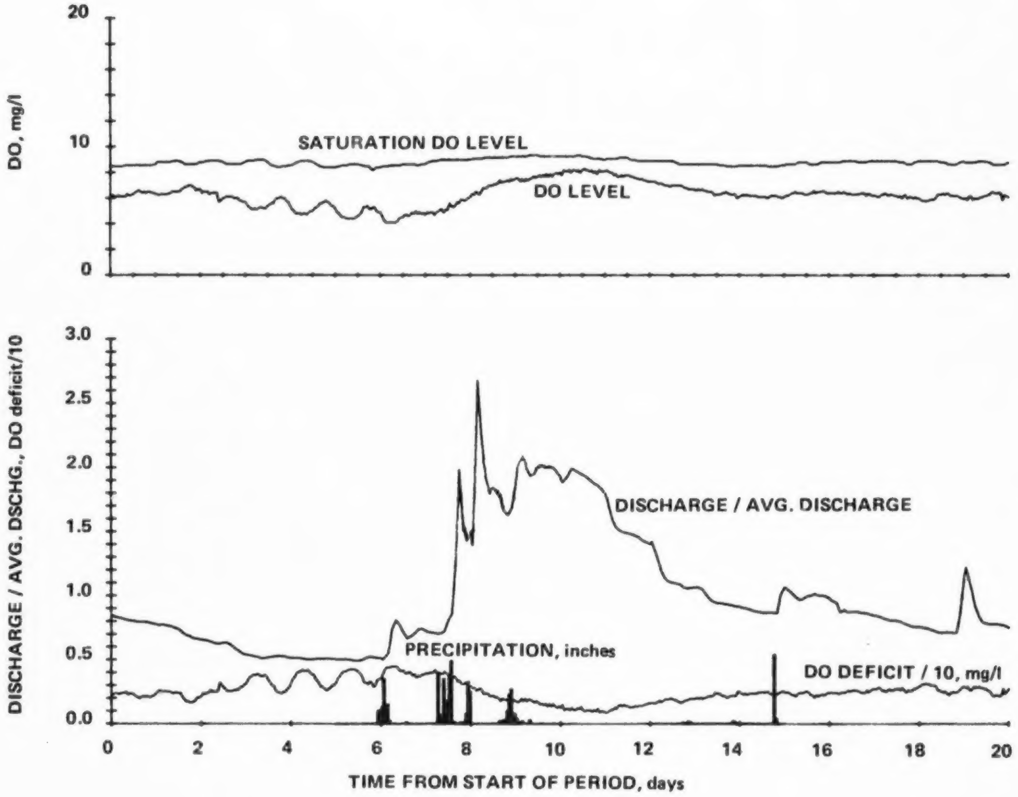

Figure D-37. Hourly data for Lehigh R. at Easton, PA.
(8/1/76 to 8/20/76).

Conclusions and Comments: There does not appear to be a real problem at this site, even though Streeter-Phelps indicates one could theoretically exist. Water quality is generally good. The D.O. generally increases with increased flow. It would be interesting to see why the D.O. seems to consistently be low at times of rainfall. The cause is not obvious.

STATE: PENNSYLVANIA

Monitor Name: Schuylkill River at Philadelphia
USGS I.D.: 01 474 500 Latitude: 39 58 00 Longitude: 75 11 20

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Western Philadelphia, Drexel Institute of Technology
Weather Bureau I.D.: 6879

Daily Data Analysis Results: Water years 1969-1972 were examined. The probability of low D.O. with high flow reached 61 percent in 1972. D.O. levels averaged 60 to 70 percent of saturation.

Quality of Records: The monitor is visited once a month or more. The flow record is continuous. The monitor record is fair with periods of up to one month missing, generally in the summer.

Discharge Characteristics: Average flow 1900 cfs, range 0-100,000 cfs

Drainage Area at Monitor: 1893 square miles

Urban Area(s) Contributing at Monitor: Philadelphia and suburbs

Approximate Urban Area Contributing at Monitor: 40^+ square miles or 2 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site

Hourly Data Analysis Results: The period examined is illustrated in Figure D-38. There is clear evidence of a D.O. deficit increase at the time of the flow event. The correlation between the rainfall and increase in flow is also clear. The D.O. drops below 5 mg/l during the event shown.

Conclusions and Comments: There is clear evidence of a correlation here. The monitor is probably not in the best location based on similar sites elsewhere. Unfortunately, it could only be moved 4 or 5 miles downstream, as the Schuylkill joins the Delaware there. The junction is just above the Delaware at Chester monitor which is discussed elsewhere. There is no question of urban area here, but other sites would be simpler hydraulically for detailed studies.

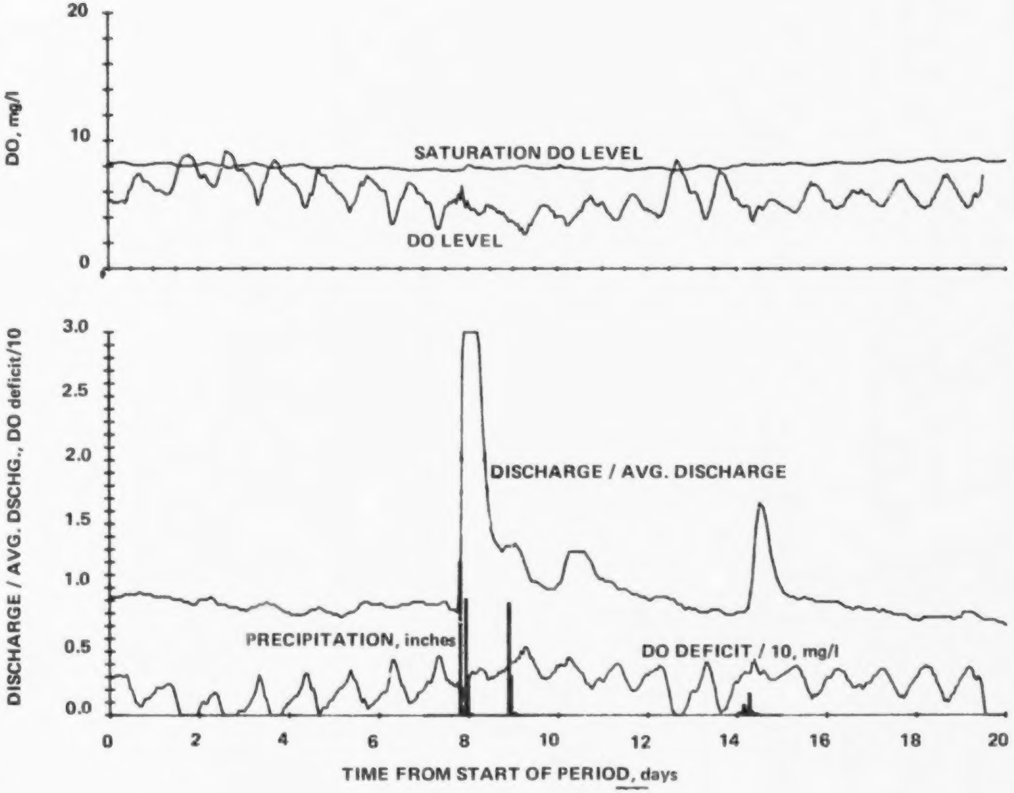

Figure D-38. Hourly data for Schuylkill R. at Philadelphia, PA. (8/19/72 to 9/7/72).

STATE: TEXAS

Monitor Name: Trinity River below Dallas
USGS I.D.: 08 057 410 Latitude: 32 42 27 Longitude: 96 44 08

Stream Gage Name: Same
USGS I.D.: Same Latitude: Same Longitude: Same

Rain Gage: Dallas FAA APT
Weather Bureau I.D.: 2244

Daily Data Analysis Results: Only water year 1977 was available, as the stream has not been monitored long. A 60 percent probability of low D.O. at high flow was computed. The dissolved oxygen level averaged an extremely low 26 percent of saturation.

Quality of Records: The monitor was serviced once a month or more. The flow record is continuous for the entire year. The monitor record was highly intermittent in the summer.

Discharge Characteristics: Average flow 2,000 cfs, range 1,000-8,000 cfs

Drainage Area at Monitor: 6278 square miles

Urban Area(s) Contributing at Monitor: Dallas-Fort Worth Metropolitan Area

Approximate Urban Area Contributing at Monitor: 724 square miles or 12 percent of total

Results of Streeter-Phelps Analysis: Not performed at this site

Hourly Data Analysis Results: Two sets of hourly data were examined for the Dallas gage as well as one for the Trinity River at Rosser, Texas. Rosser is some 40 miles south of Dallas and seemed to be in a better position to sense a deficit in the Streeter-Phelps sense. All three data sets are illustrated in Figures D-39, D-40, and D-41. There is no doubt that a problem exists here. The flow of the Trinity is almost all treated sewage under low flow conditions. The D.O. is often zero during flow events. Note that even at Rosser the D.O. goes to zero with a flow event.

Conclusions and Comments: The Trinity River below Dallas has some of the worst water quality encountered anywhere in this study. During summer low flow periods, the river is primarily treated sewage effluent. It would be par-

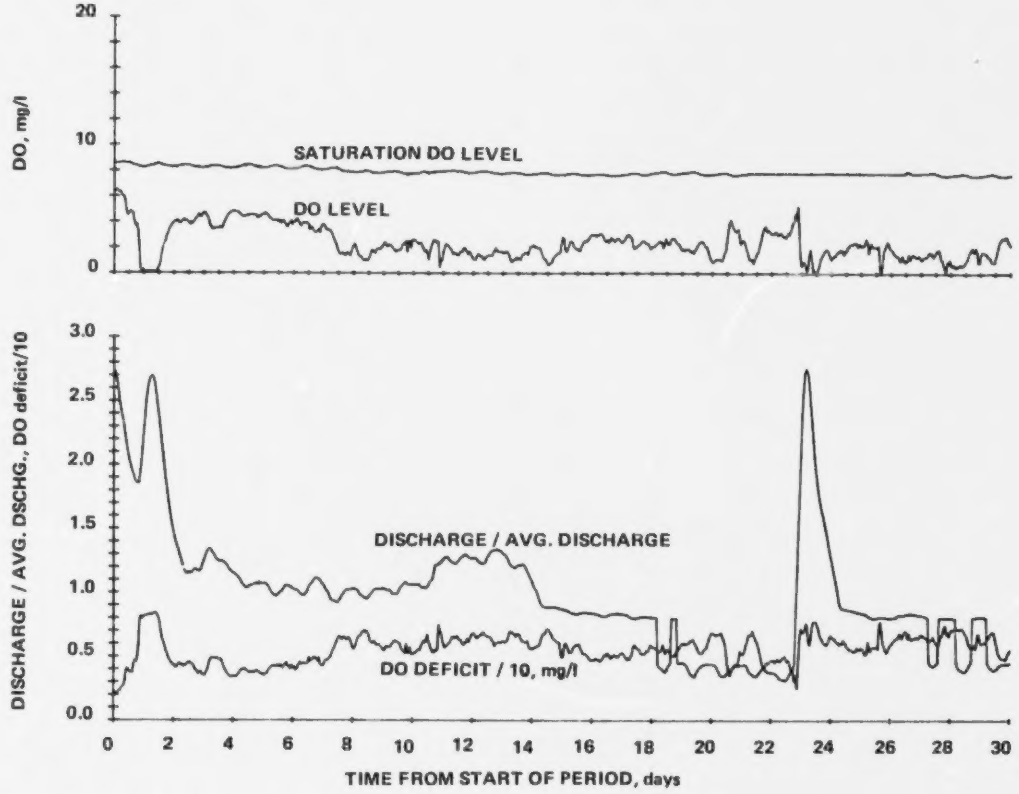

Figure D-39. Hourly data for Trinity R. below Dallas, TX. (5/21/77 to 6/19/77).

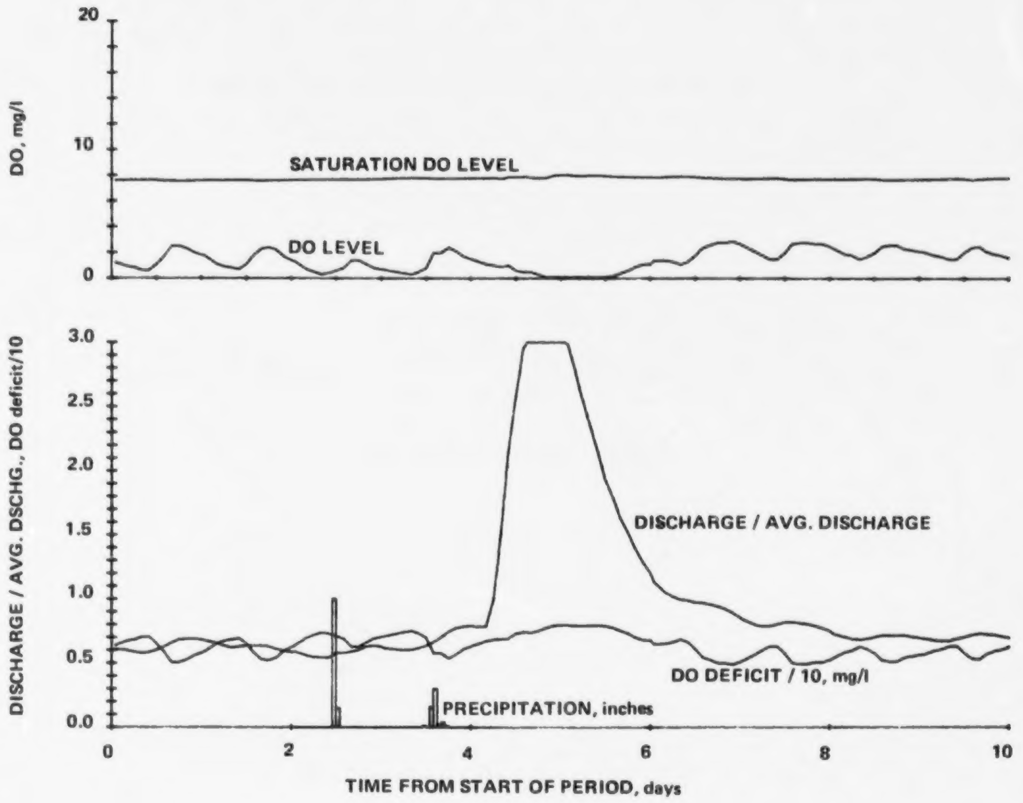

Figure D-40. Hourly data for Trinity R. near Rosser, TX.
(9/4/77 to 9/13/77).

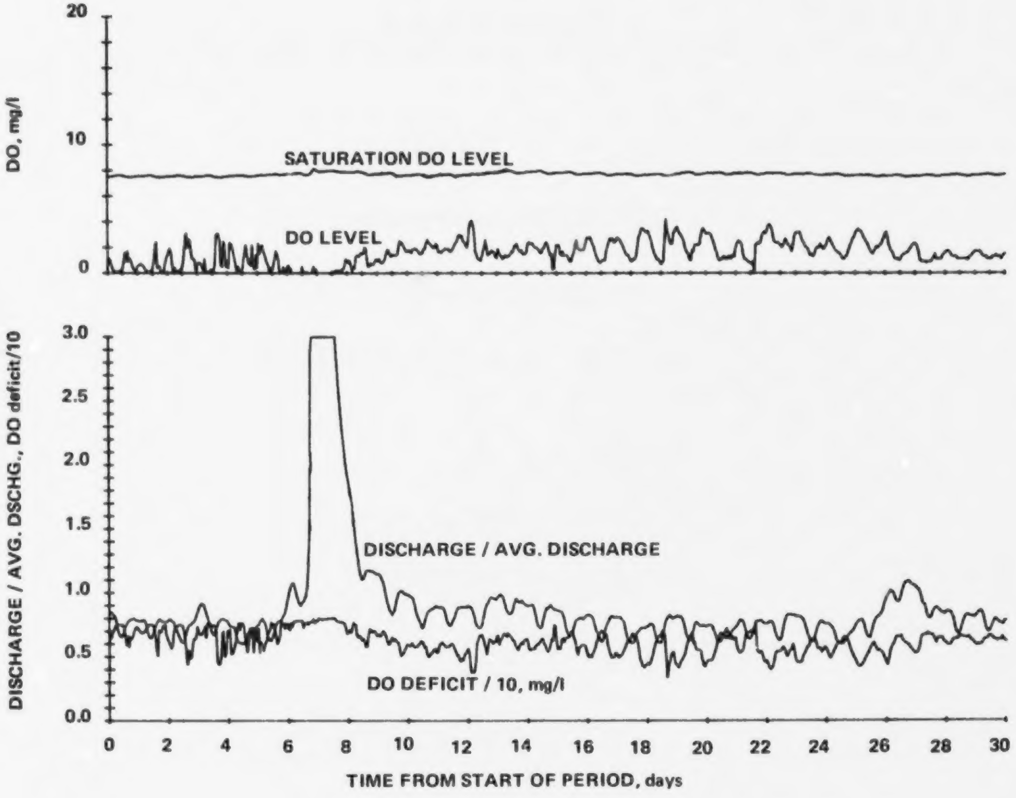

Figure D-41. Hourly data for Trinity R. below Dallas, TX. (9/1/77 to 9/30/77).

ticularly interesting to see exactly what causes the D.O. to go to zero when flow increases. This is perhaps a reintrainment of oxygen demanding material. The urban area involved is very large and a rather expensive sampling program might be required to adequately define the problem.